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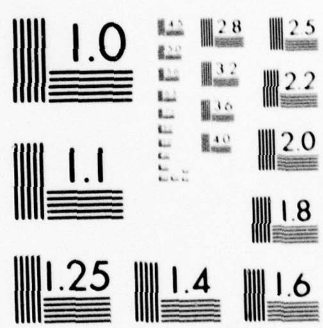
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HELMET-MOUTED SIGHT/DISPLAY PROGRAM
CESSNA 310 FLIGHT TEST

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JULY 1979

AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Aerospace Medical Research Laboratory

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The first phase of an engineering flight evaluation of operator performance with a Helmet-Mounted Sight/Display system has been completed. A total of 22 flights were conducted during which subjects utilized a helmet-mounted sight to control the pointing direction of a gimballed television camera and a helmet-mounted display to view the picture from the TV camera. Particular attention was paid to any indication of disorientation or discomfort attributable to the helmet-mounted equipment. No signigicant effect was noted.

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20. Secondary investigations considered the effect of servo dynamics in the TV camera system, angular motion limits in the pointing system, display field for view, display brightness, and environmental factors including target complexity and contrast, ambient brightness, and atmospheric haze. Interaction between the ambient scene viewed directly and through the combining glass of the helmet display caused no difficulty during the experiment.

A second phase of this study considered the potential for inducing vertigo through the use of helmet-mounted equipment. The test plan and preliminary results for this experiment are presented in an appendix to this report. A detailed report on Phase II will be issued later.

CONTENTS

ILLUSTRATIONS

SECTION I
INTRODUCTION AND SUMMARY

INTRODUCTION

A Honeywell-owned Cessna 310 aircraft was used in a flight test program to study certain aspects of a helmet-mounted display. This program was planned and conducted on internal development funds to increase Honeywell's overall background in using helmet-mounted sight and display equipment, especially through flight experience. This program evaluated a see-through display concept.

The objective of the ongoing HMS/D program is to design, develop, and fabricate an IHMS/D that can be used efficiently and effectively in visually coupled systems. The system would provide a capability for aiming and tracking while simultaneously viewing information developed from airborne systems or remote sensors. The program is directed toward producing a flightworthy system which is acceptable to operational personnel.

The program calls for integrating current Honeywell capability in the design, development and production of a visor-projected helmet-mounted display. Various models of the helmet-mounted display reflect the improvements and modifications in the program as they are built. In turn, certain aspects of the development program are dependent on the completion of tests and/or experimentation. A few of the design criteria are based on results of flight test programs since flying is a logical "end use" of the system.

The present multi-phased flight test program was started to solve some of the basic VCS problems which were unique and could only be solved in flight. Several problems were described and the possible solutions to these problems were examined. After discussions of display presentation alternatives it was

decided to install a TV camera in a gimbal and vector the camera using a helmet-mounted sight system. As various aspects of the aircraft installation were discussed, the program grew to its present dimensions. The flight test helmet display unit is illustrated in Figure 1-1. This test fixture has a Honeywell-developed, side-mounted monochromatic cathode ray tube (CRT) which provides the wearer with a projected image covering a 40-degree field of view. The custom compound optics project the CRT image onto a combiner in front of the wearer's right eye. This combiner presents to the helmet wearer a collimated image overlaying the ambient scene viewed through the combiner and also viewed by the left eye.

SUMMARY

Twenty-two flights were flown to evaluate the performance of the helmet-mounted display. Eleven engineer subjects were used in the tests. Three of the subjects had aeronautical ratings of private pilot or higher.

There was no disorientation reported by the subjects. Three subjects developed weak headaches and/or slight feelings of nausea.

Turbulence effects were more important to system dynamics than the camera system servo response. The operator's sitting height and thus his head position in the light envelope is also more important to the system dynamics than camera system servo response. The sensor system had a limit program built-in so that if the helmet sight was moved outside of the preset limits in either axis, the command was cut out in both axes. Quite often the subjects would lift their head above the horizon which was outside of the limit in pitch; and azimuth commands to the camera were cut off. The camera would not move until the head line-of-sight was within the envelope of both axes. This feature gave the projected image a very jerky response in the tracking tasks.

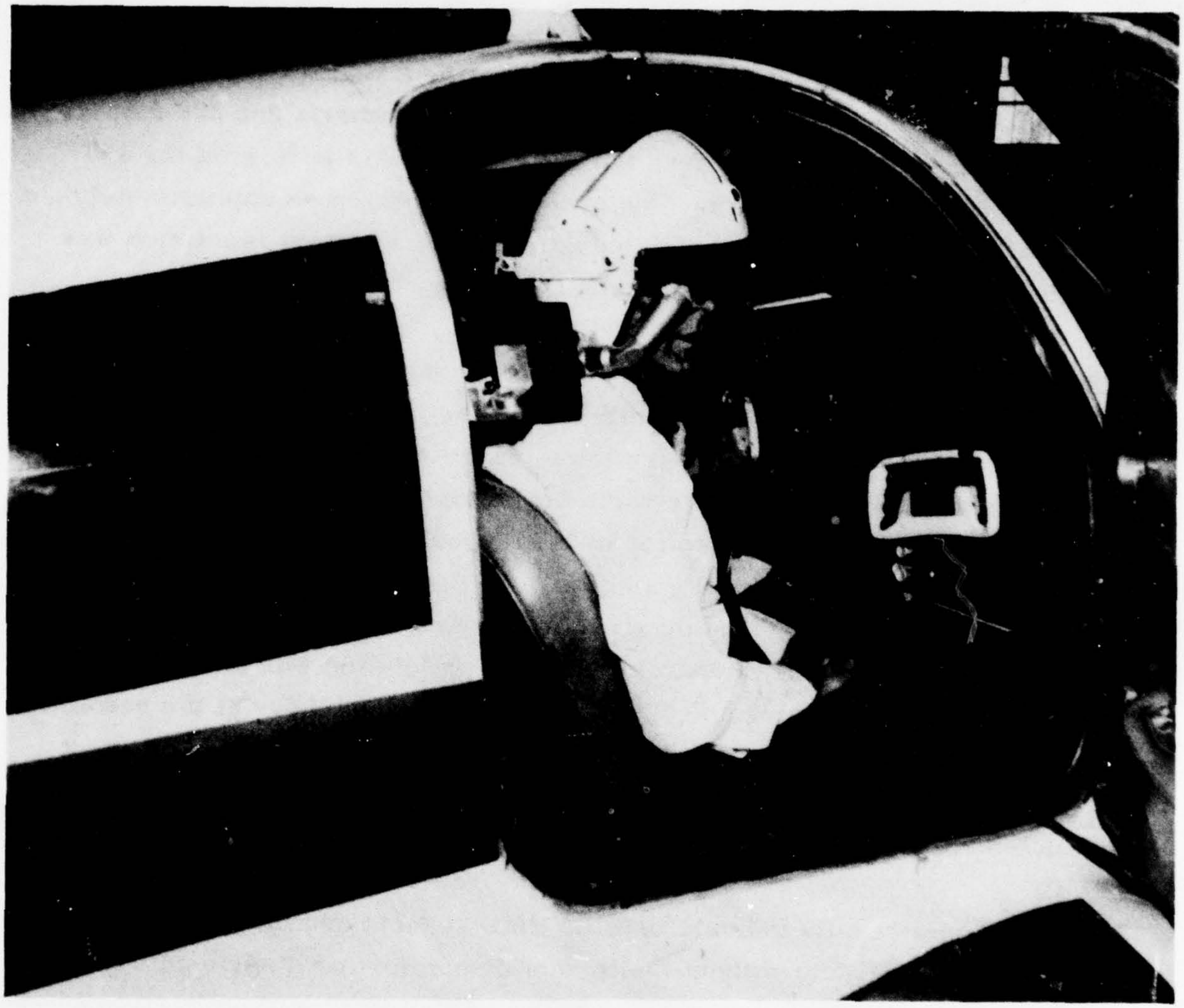


Figure 1-1. Helmet Display Unit

Once a target was acquired, tracking it was not a problem. The tracking capability of the subject with the HMD system was evaluated versus two fields of view, 20 deg and 40 deg. There was no difference in tracking performance versus field of view.

Two display brightnesses were evaluated, 150 foot lamberts and 300 foot lamberts measured at the CRT face plate. The subjects perferred the 150-foot lambert display brightness. The system resolution was approximately 4.5 $\overset{\frown}{\text{min}}$ at 150-foot lambert display brightness. The system resolution was approximately 6.5 $\overset{\frown}{\text{min}}$ at 300-foot lamberts display brightness.

Target complexity, contrast, brightness and atmospheric haze are signficant factors in range of detection of the target with the HMD. One measure of performance of the HMD in these tests was range of detection. On a given day with a given subject the above variables were the most significant factors in determining the range of detection of the targets. The average ranges of detection for all subjects for all conditions are described in Figure 3-4. HMD resolution measured inside and outside the hangar demonstrate the effect of light on the target. Inside the hangar the HMD resolution was one $\overset{\frown}{\text{min}}$ less than the resolution on the ramp. The incident light brightness at the resolution chart was 65 foot candles apparent inside the hangar. The average incident light brightness at the resolution chart was 2000 foot candles apparent on the ramp outside the hangar.

These flight test results indicate that the HMD concept can be used to detect and track ground targets without feelings of discomfort or disorientation. Problems were identified that indicate further flight testing should be conducted.

SECTION II
FLIGHT TEST PROGRAM

BACKGROUND

The program was divided into two phases to accommodate two different sets of problems. Phase I evaluated the helmet wearer's performance versus design variables such as image field of view, display brightness, display contrast, scene brightness, altitude, visor transmission, etc. Phase II investigated potential problems of vertigo and related visual perception to the user of the helmet-mounted display system. Phase II results will be reported in detail in a separate report.

A primary objective of the Phase I flight test with the helmet-mounted display was to record and evaluate any effects of disorientation of the subject while observing targets through the see-through projected image display. A secondary but very important objective of the flight test program was to answer operational questions to help establish design criteria for the HMS/D systems. There was the basic question as to whether the helmet wearer could recognize targets on the helmet-mounted display. Once a target was of 20- and 40-degree field of view also had to be resolved. Human nature tends to favor a 40-degree field of view since the picture is wider but this wide-angle feature adds to the system cost and complexity. Both of the fields of view were provided and data were taken on the subject's ability to acquire targets. In terms of the helmet wearer's performance, what are the effects of combiner size, lens size, image size versus real-world size and the sensor control upon the system design?

The effects of cockpit lighting, projected image brightness and the real-world scene brightness had to be evaluated. The real-world scene color, contrast, and brightness versus the season of the year had to be evaluated. The influence of range of detection of "small" targets was a significant design question. As with other design problems, the answers appeared after several flights but the questions and answers had to be documented with facts to establish the necessary HMS/D system design criteria.

AIRCRAFT INSTALLATION

The Honeywell Cessna 310 is a two-engine, propeller-driven, normally four-passenger aircraft (Figure 2-1). With the rear seat replaced by a single seat, the available space is used to mount the TV monitor, inverters, power supplies and control units. However, because the aircraft is shared with another project, several potentially helpful modifications have not been made.

The nose of the aircraft was first considered as the logical location for the gimballed camera since the view is unobstructed. However, since this area is crowded with electronic equipment, air ducts and nose wheel, it would have been necessary to mount the camera external to the nose. The alternate location selected was a 6-inch hole in the floor of the baggage compartment which had been used for ordnance drops. This location requires that the camera be mounted vertically with some form of prism or mirror at the lower end to scan the terrain in pitch. It also requires that the camera assembly and the prism rotate in azimuth with the pitch servo on the inner gimbal.

The camera, with manual controller, is shown in Figure 2-2. A Cohu 2054-024 model camera was inserted in a 3-inch aluminum tube with the lens extending to 5/8-inch above the prism. A prism (Figure 2-3) was selected as superior to the mirror since a prism's reflecting surface is smaller than a comparable

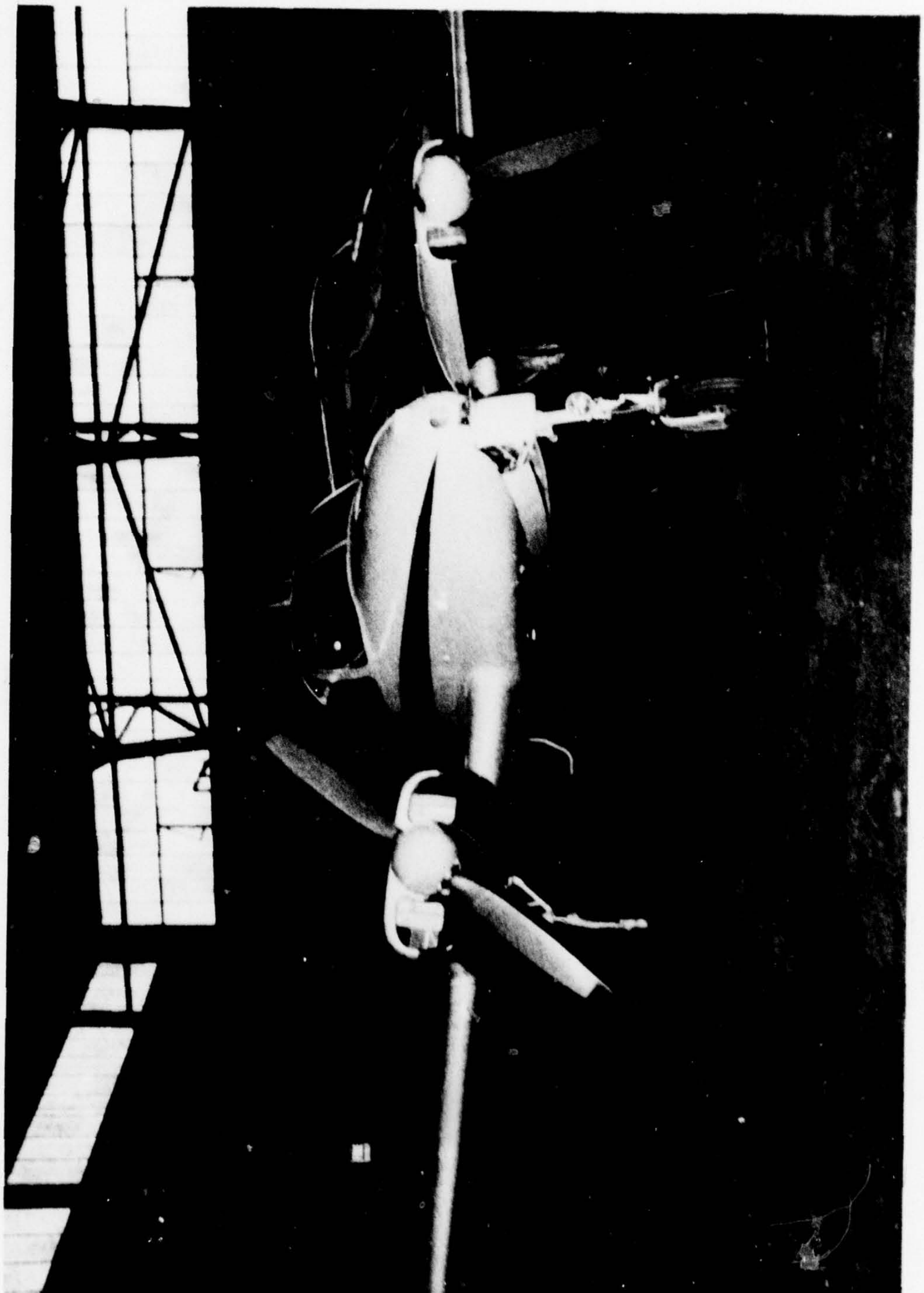


Figure 2-1. Honeywell Cessna 310 Test Aircraft

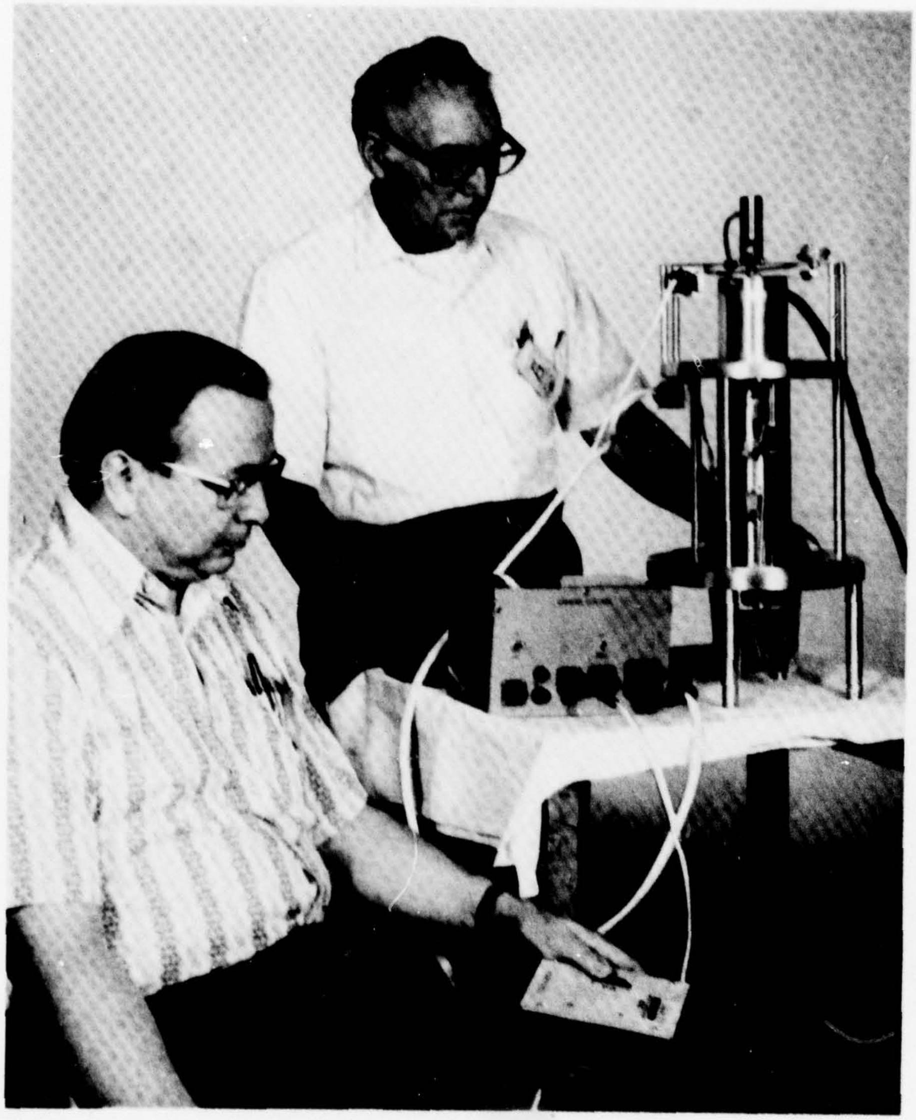


Figure 2-2. Camera Gimbal with Manual Control

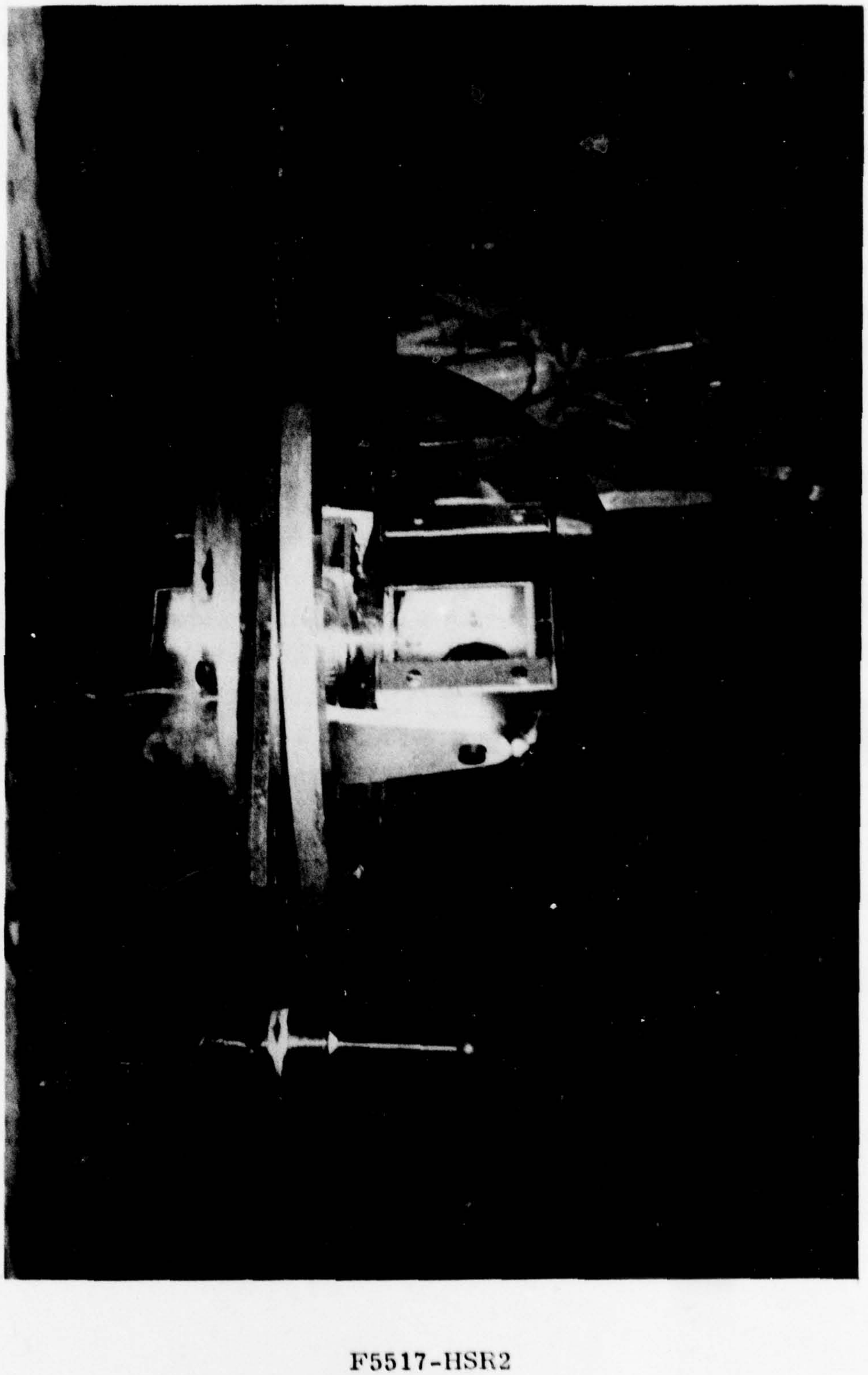


Figure 2-3. Camera Prism and Dome

mirror. In this case, size is more important than weight because the acrylic dome has to be kept to a 9-inch diameter or less. The camera cable was routed up and then looped forward to a TV camera control unit. Because the original cable was too stiff the heavy rubber insulation was removed, the braided grounding sheath replaced with a single wire, and a flexible plastic outer sheath added.

The camera is mounted within a 3-inch aluminum tube (Figure 2-4) to provide for easy camera removal. A set screw and window on the side of the tube provides a lock for the camera and an index for the camera alignment. The horizontal sweep leads in the camera are reversed to correct the reflecting prism-reversed image.

The right-angle prism is 63 mm square on the viewing side and silvered on the reflective surface. The cavity for the prism is coated to prevent unwanted reflections. The prism is pivoted at a point of intersection of the lens center-line and the reflective plane. It is mounted 5/8 inch from the end of the lens holder, which is sufficient clearance to allow about 25 degrees pitch travel (22-1/2 degrees nominal travel -- see Figure 2-5). Pitch angular motion is obtained through a lead screw arrangement with a 1/4 inch, 18-thread screw. The upper end has a small "U" joint to account for angular motion of the drive shaft and servo misalignment. The feedback linkage to the 1K film potentiometer has a multiplication of three so that the travel becomes 67-1/2 degrees at the potentiometer arm. A mechanical stop is provided outside the normal limits although zener diodes provide the first limit. In the pitch axis, if the electrical limit is exceeded the physical limit is a hard stop.

The pitch servo motor is a size 15 with a 40-volt control voltage, 4700 rpm, 1.45-oz inch stall and a motor generator output of 3.1 volts per 1000 rpm. A gear reduction of 5.95 to 1 is used between the servo and the screw drive.

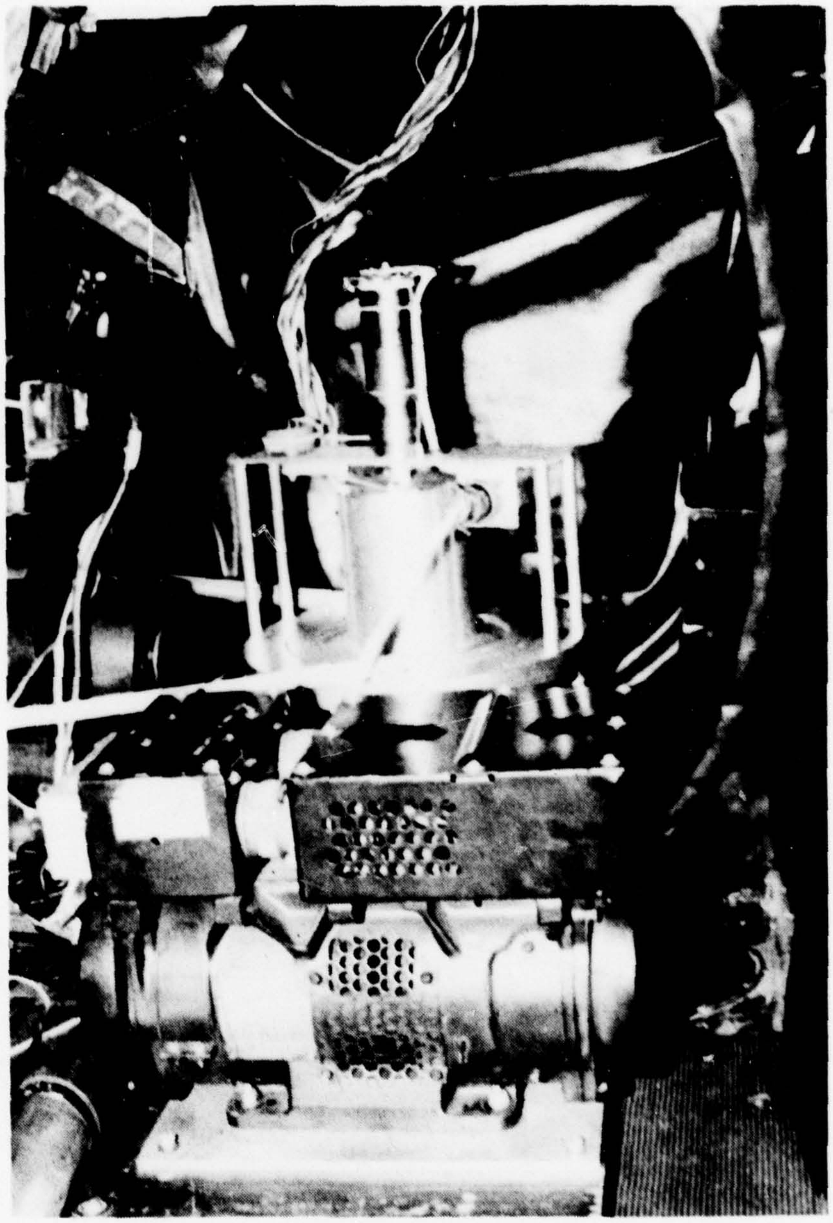


Figure 2-4. Equipment Installation

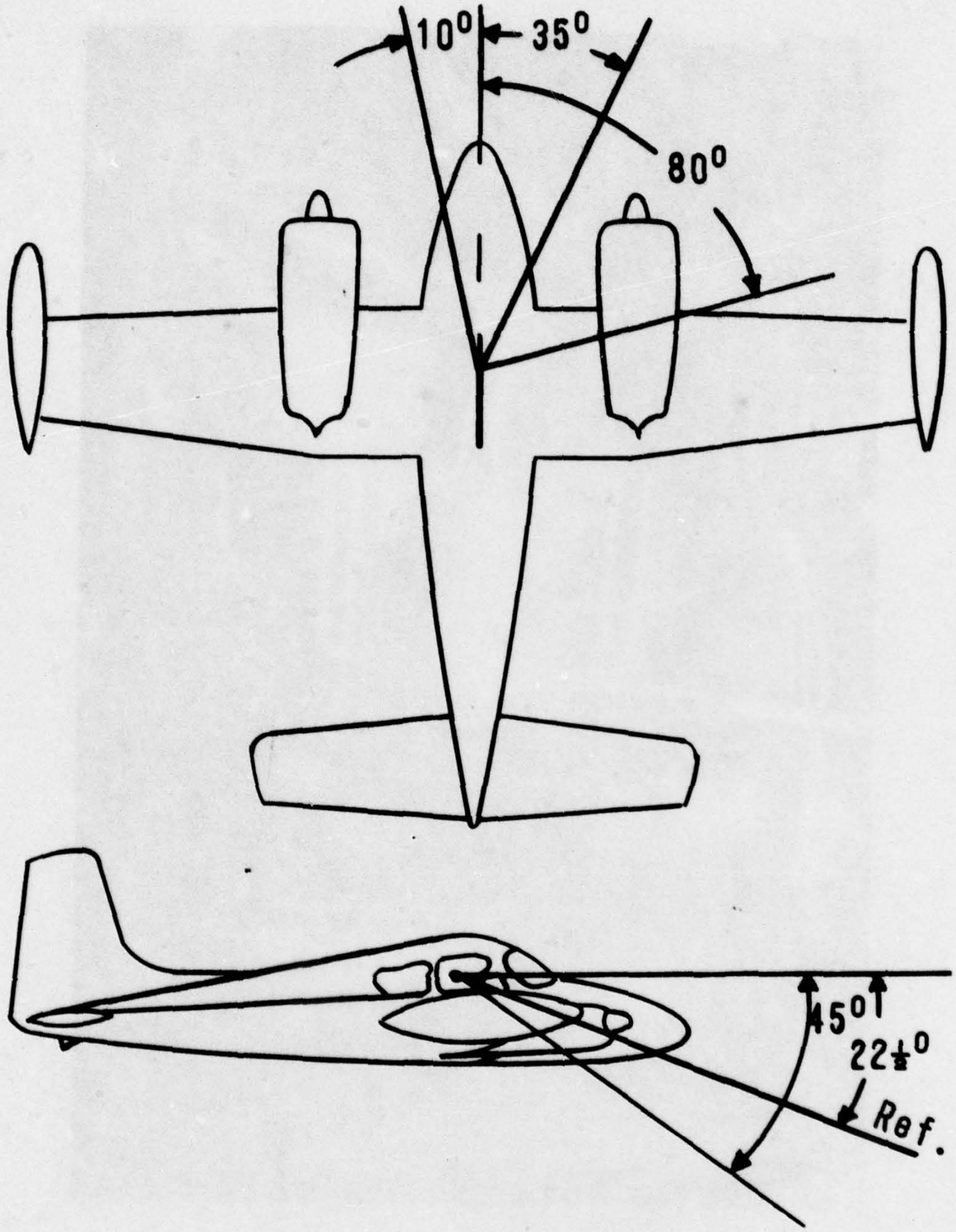


Figure 2-5. Helmet Sight Geometry

In azimuth, a size 15 servo similar to pitch is used with a 60.92 to 1 gear reduction. Since the azimuth travel is -10 degrees and +80 degrees (to the right) a one-to-one linkage to the feedback potentiometer is used.

The camera used in flight test is a Cohu 2054-011 with a 25 mm lens. The unit is 3 inches in diameter, 8-7/8 inches long and weighs 4.5 lb. The 25 mm lens has openings of f1.4 to f22 and a focus adjustment of 2 feet to infinity. The viewing angle of the camera is 28 degrees horizontally and 21 degrees vertically.

The servo amplifiers use d-c inputs from the hand controller or the helmet sight to drive the camera. The d-c inputs are summed with the d-c potentiometer feedbacks and the velocity feedback. An electromechanical chopper is used to convert the dc to ac for the servo amplifiers. At first a 3.5-watt amplifier was used but was later replaced with a solid-state 9-watt unit which was more compatible with the flight test requirements.

The power required for the various units varies from 400 cycle, 3 phase to 110 volt, 60 cycle and ±15 volts dc. The 400-cycle, 3-phase inverter has an output of 750 volt amperes while the 60-cycle inverter has a 250-volt ampere output. A surplus (MB-5 Honeywell autopilot) 28-volt power supply is used to provide the ±15 volts for potentiometer excitation.

Externally, the prism extends below the aircraft, is protected by a 9-inch diameter acrylic dome,and has a retainer ring to attach it to the fuselage. The 1/4-inch-thick dome is periodically removed for cleaning or quick adjustment of focus or lens opening. For most flights the lens opening is kept at f16, one stop below full opening.

In the cabin, the helmet sight display unit, helmet sight power unit, servo control unit, 9-inch TV monitor and helmet sight switch are all mounted on a flat table. A TV control unit, the d-c power supply and a fire extinguisher

are mounted on the lower shelf. The intercom between subject and flight engineer is usually stored on a shelf when not in use.

The helmet sight light sensor is located on a removable bracket on the door post between the subject and flight test engineer. This must be quickly removable since, in the event of a ground emergency, all three occupants would use this exit. As normal procedure, these light sources are removed for landings and takeoffs. A block diagram of the system is shown in Figure 2-6.

FLIGHT TEST PLAN

The Honeywell Cessna 310 was requested for a period of 6 months during which the aircraft was to be used on a weekly basis for flight testing. The Cessna was equipped with a 2000 series COHU TV camera, servo-driven in pitch and azimuth in response to helmet sight inputs. The terrain picture seen by the TV camera was projected on the helmet mounted display for the test subject and on a 9-inch TV monitor at the rear seat for the flight test engineer.

The flight test plan arranged the design variables in systematic order. These variables included field of view, monocular versus binocular vision, visor transmission, sensor-display scaling or size, and various types of visors. A series of flights was planned to familiarize some of the subjects with the equipment and to make changes before data were taken. Table 2-1 describes the general test plan.

The route was laid out to include various types of targets and to use about 1 hour of flight time. The course can be flown clockwise or counterclockwise to test the effects of sun angle on the helmet sight and display performance. The test course is detailed in Figure 2-7. The numbers on each leg of the flight plan refer to separation of targets in minutes of time.

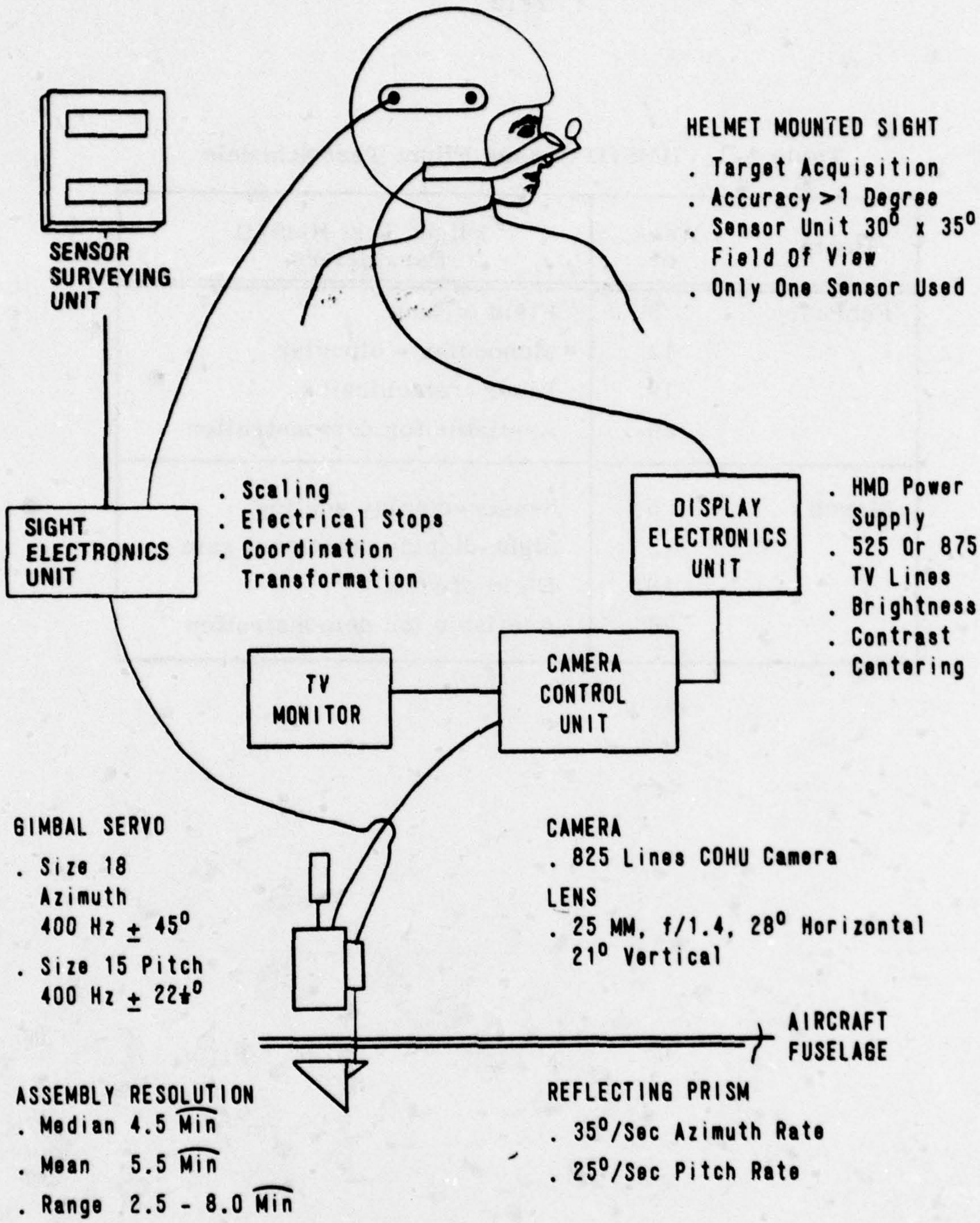
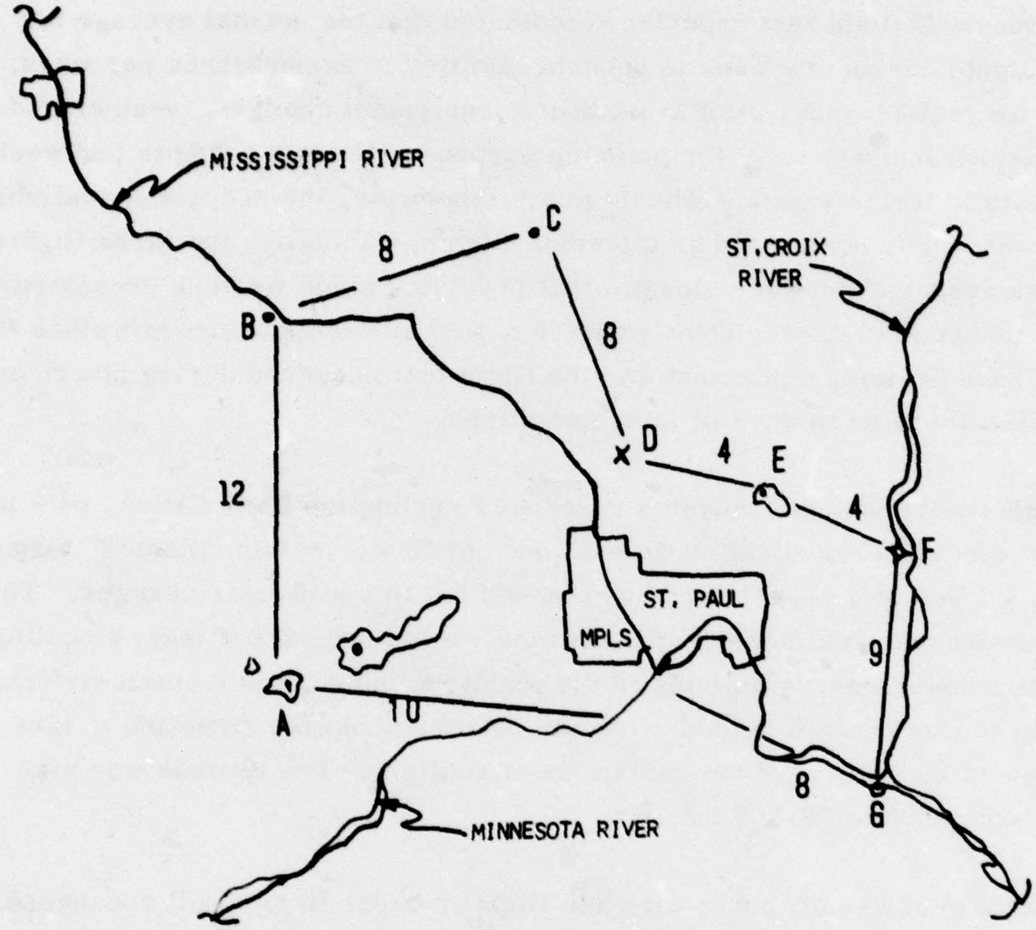


Figure 2-6. Block Diagram of Flight Test System

Table 2-1. HMS/D Cessna Flight Test Schedule

Month	Week of	Flight Test HMS/D Parameters
February	5	Field of view
	12	Monocular - biocular
	19	Visor transmission
	26	Available for demonstration
March	5	Sensor-display scaling
	12	Sight-display rotational gain
	19	Field of view
	26	Available for demonstration



HELMET DISPLAY FLIGHT PLAN

A ISLAND IN LAKE WACONIA
B NSP STACK AT MONTICELLO
C HOPG AT ST. FRANCIS
D ANOKA COUNTY AIRPORT
E ISLAND IN WHITE BEAR LAKE
F NSP STACK AT BAYPORT
G BRIDGE AT HASTINGS

Figure 2-7. Target Locations

Past Honeywell flight test experience indicated that the normal average for useful flights during any week is probably limited to around three per week. Delays for maintenance, pilot availability, equipment changes, weather and other factors indicate that, for planning purposes, the three flights per week is realistic. If this schedule should prove otherwise, the additional available flights were to be designated as alternate flights. Actually, the three flights per week averaged out very close to that predicted since weather prevented flights for about 10 days. The Cessna is not an all-weather aircraft since it doesn't have de-icing equipment and the flight test occurred during March and April when there were days of icing conditions.

The flights were scheduled over a route surrounding the Twin Cities, with the targets selected after some consideration. At first, certain "planted" targets such as a truck at a crossroad were planned but this was later changed. The targets selected were more prominent objects: an island in a lake; a cooling tower at a powerplant; a building in the woods; a bridge; and a small airfield. The course was flown in a clockwise and counterclockwise direction to take into account the effects of the variations of sunlight. The altitude was also varied from 2000 to 10,000 feet.

A preflight plan was prepared for each flight in order to brief all concerned as to the objective. The flights were planned a week in advance to aid in the scheduling of pilots, subjects and observers. The plan contained the following information:

- Purpose of flight, date and time
- Pilot, observer and flight test engineer
- Special equipment, procedures, speeds, altitude and targets
- Special comments such as alternates, in the event visibility was poor

A briefing session was held before each flight to outline the order of the tests, the ground targets that must be acquired and the method of rating the performance. During the flight, information such as cloud cover, visibility, light meter readings, presence of fog or ground haze and other weather factors were noted.

During the flight, the subject was asked to acquire and track certain ground objects identified in pictures during the briefing session. Performance was monitored by the flight test engineer in the third seat who had a 9-inch TV monitor with the same picture as the observer.

After each flight, the pilot, observer and flight test engineer had a debriefing session to register all results. These results were tabulated in a flight test report, kept in the flight test log book. At weekly intervals, a memo was issued on the results of flights during the week. With the log book approach, the information was recorded while it was still fresh in everyone's memory.

Candidate targets were photographed and the test targets were selected during the debug flights and during the indoctrination flights. These targets are shown at various ranges and approach headings in Figures 2-8 through 2-21. The photographs can be misleading in that the camera field of view is wide and the target in many cases looks obvious but in reality is difficult to find under actual test conditions. These photographs were used during the briefing session to identify the targets for the subjects.

In order to maintain uniformity on the helmet display tube, it was brought periodically into the lab for calibration and check. This check consisted of a brightness reading with the photometer and a check of the 10 shades of grey on the standard TV chart.

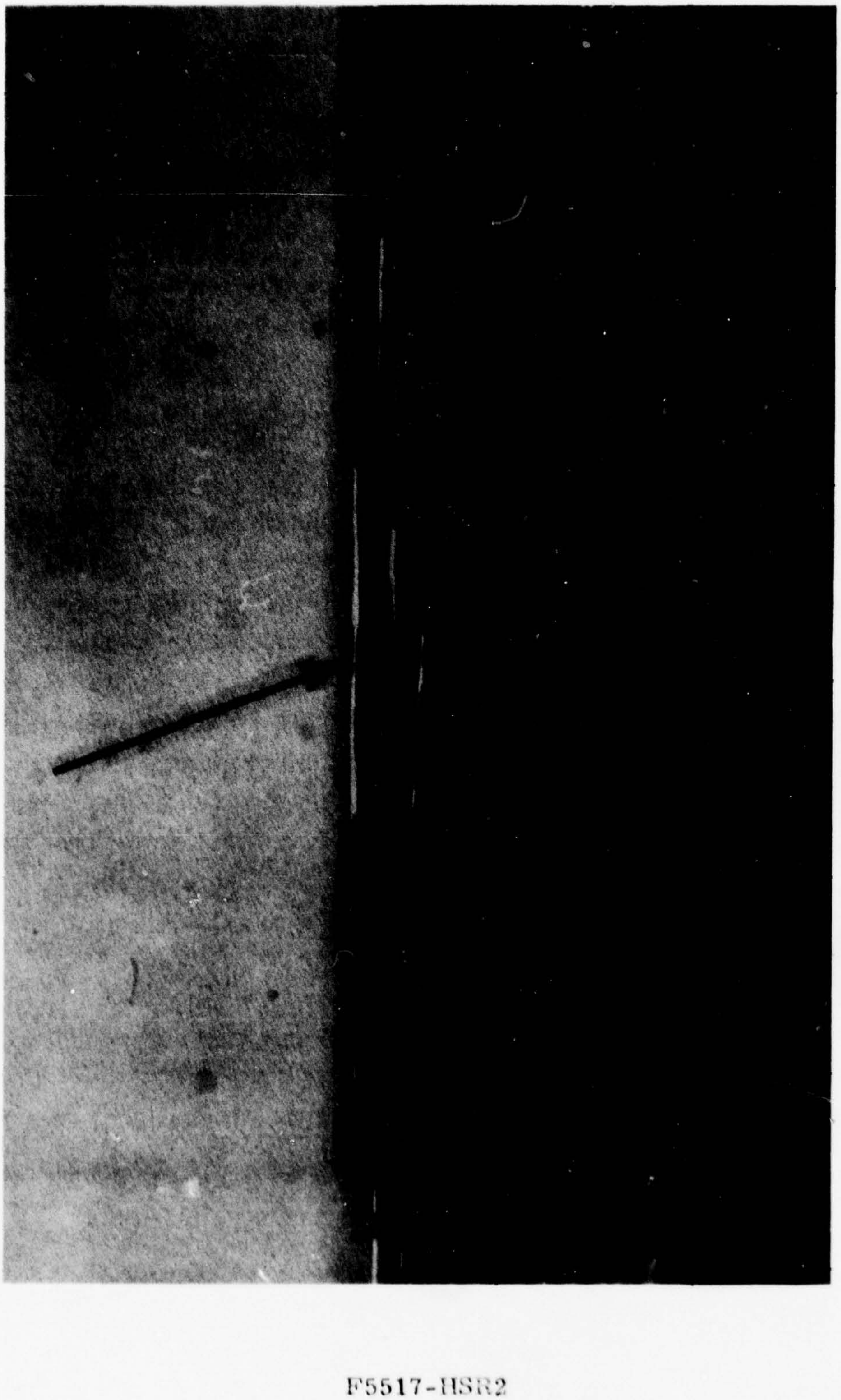


Figure 2-8. Target A Island in Lake Waconia
14 nm Range - Heading 175 deg

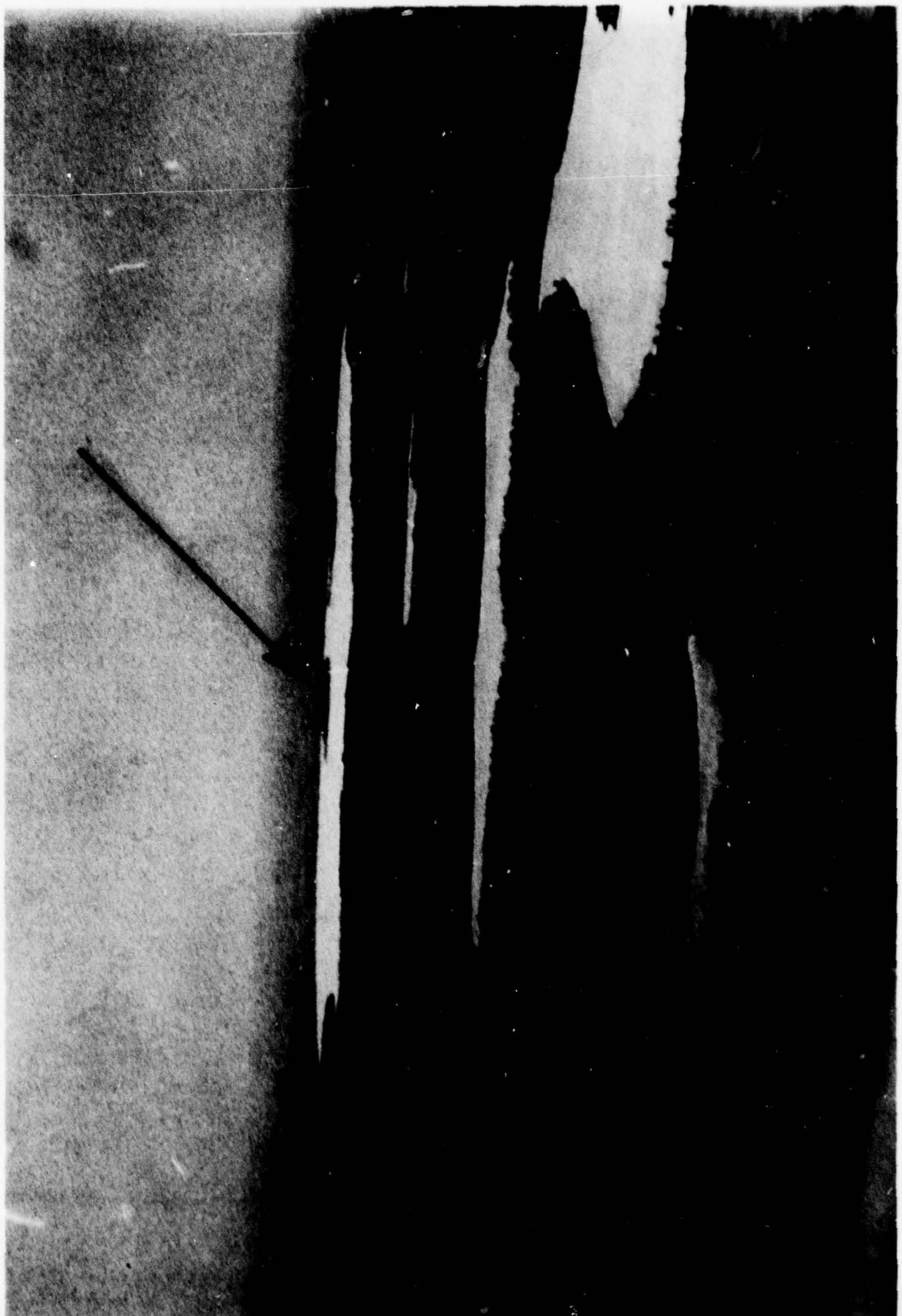


Figure 2-9. Target A Island in Lake Waconia
6 nm Range - Heading 175 deg

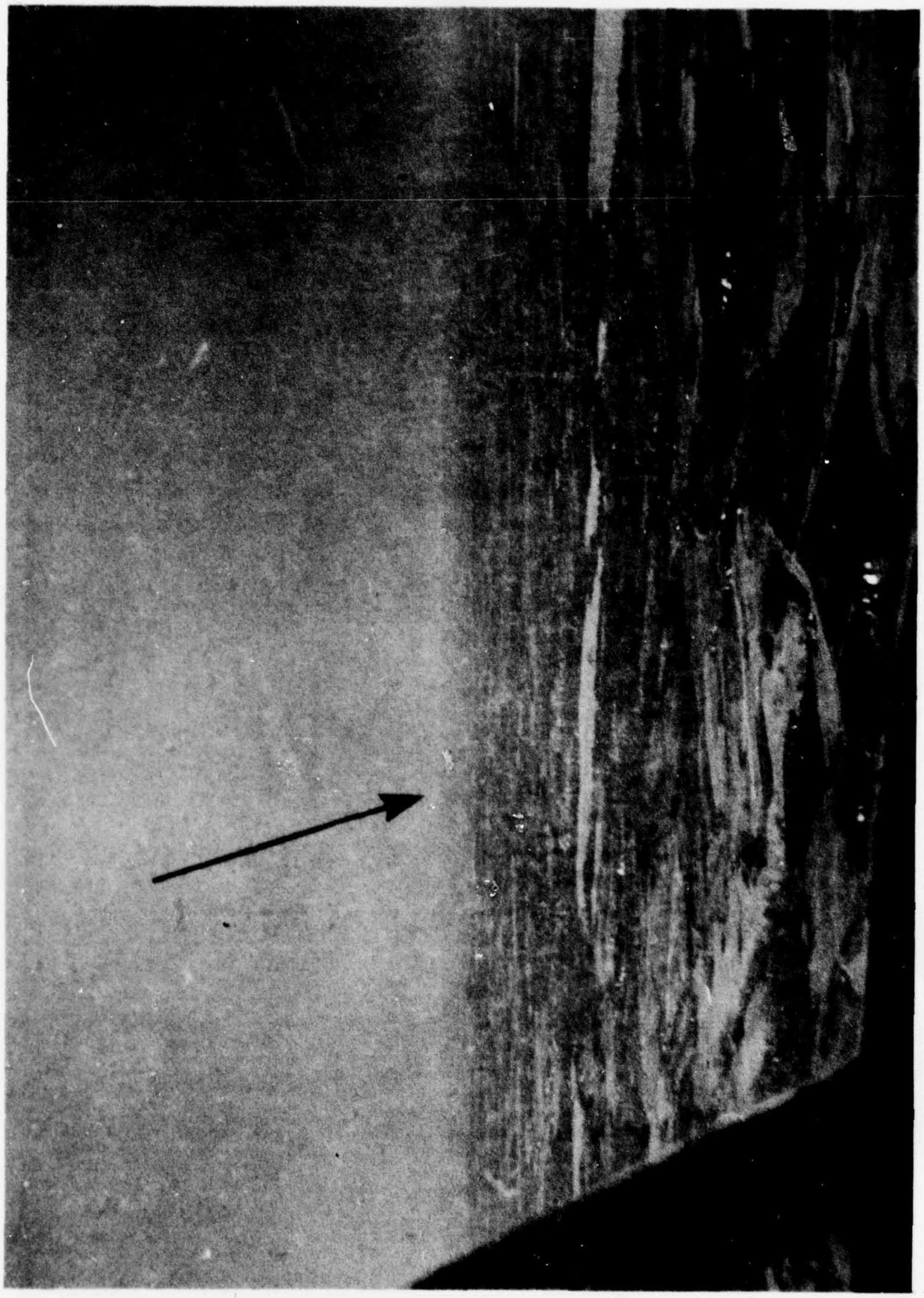


Figure 2-10. Target B NSP Stack at Monticello
8 nm Range - Heading 255 deg

Figure 2-11. Target B NSP Stack at Monticello
3 nm Range - Heading 285 deg

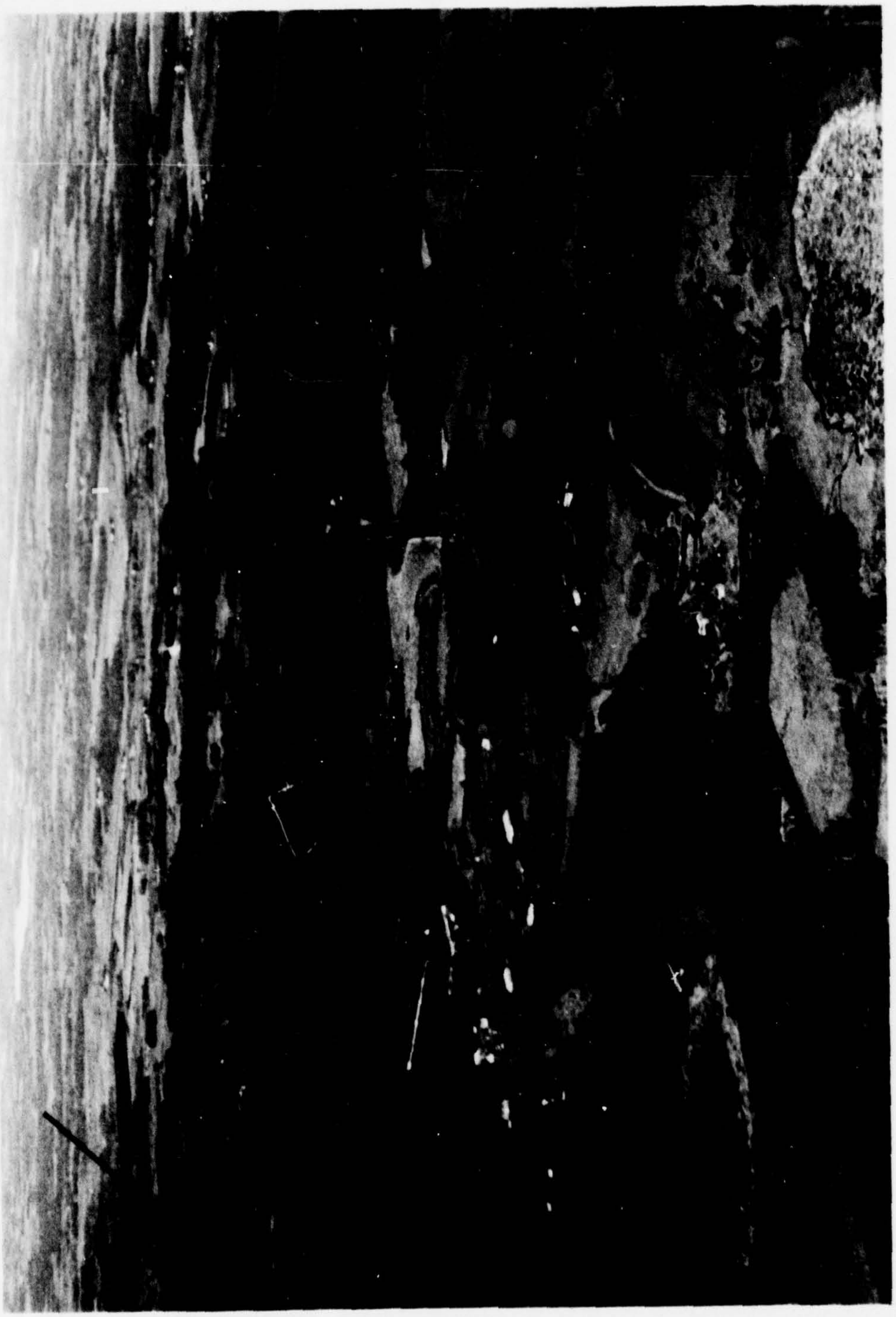


Figure 2-12. Target C Proving Grounds at St. Francis
3 nm Range - Heading 75 deg

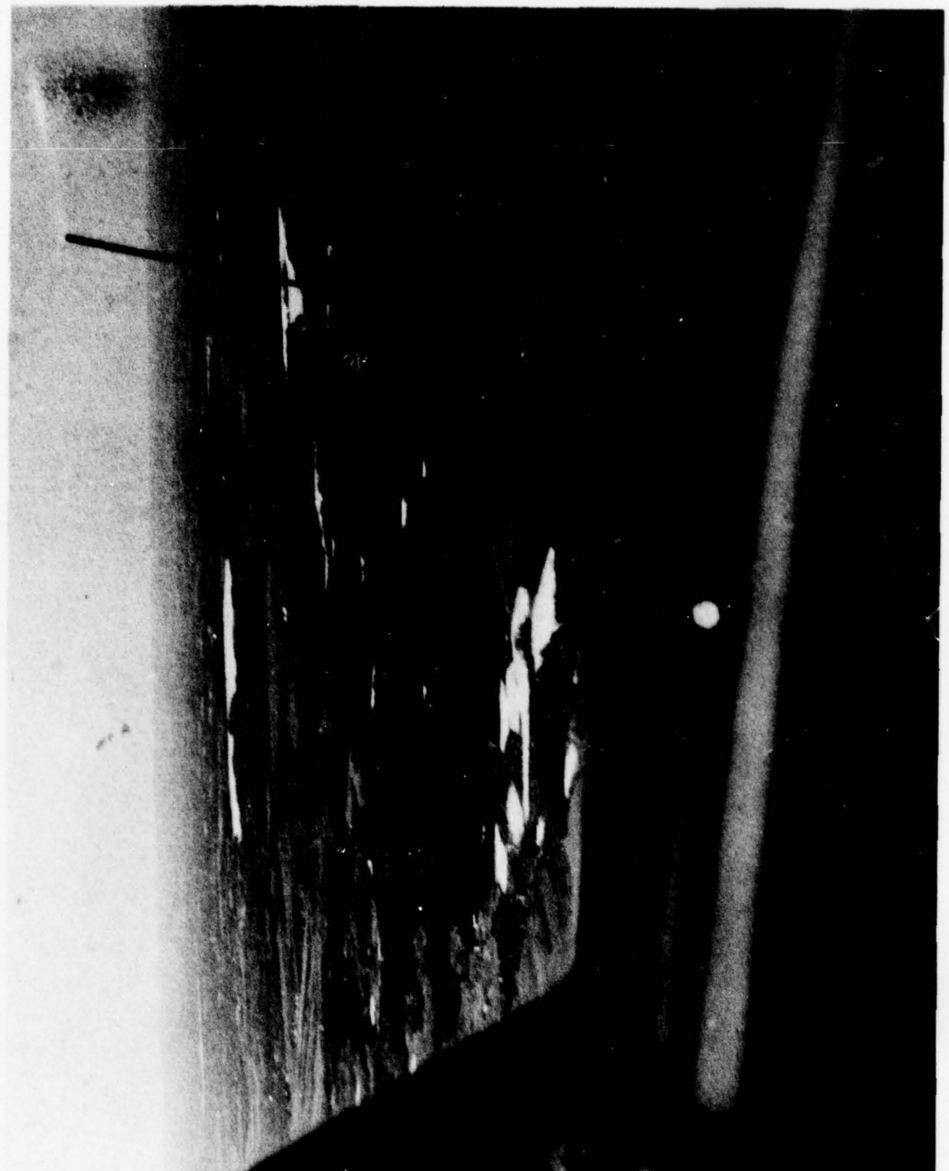


Figure 2-13. Target C Proving Grounds at St. Francis
3 nm Range - Heading 320 deg

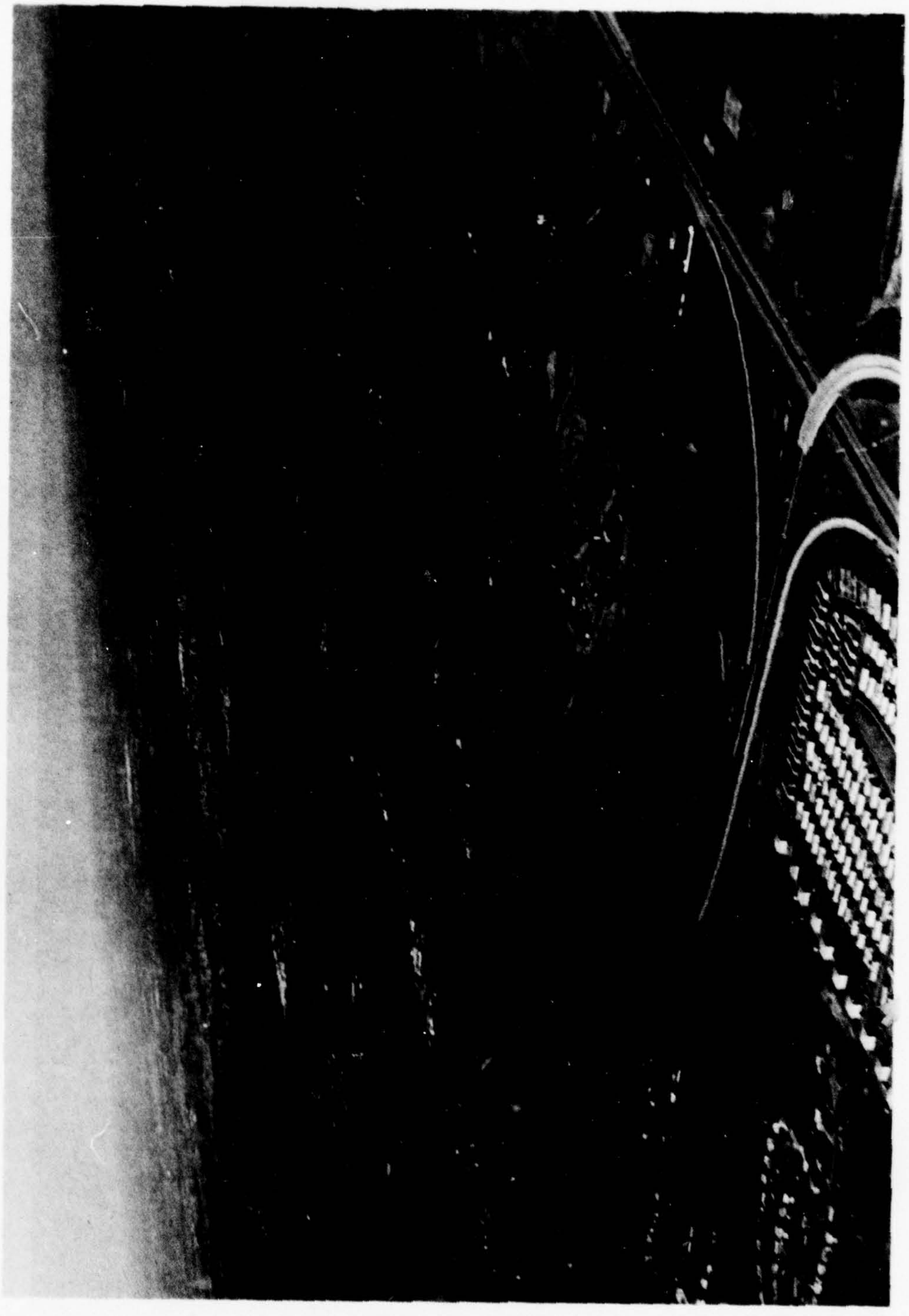


Figure 2-14. Target D Control Tower Anoka
4 nm Range - Heading 320 deg

Figure 2-15. Target D Control Tower Area 3 nm Range - Heading 320 deg

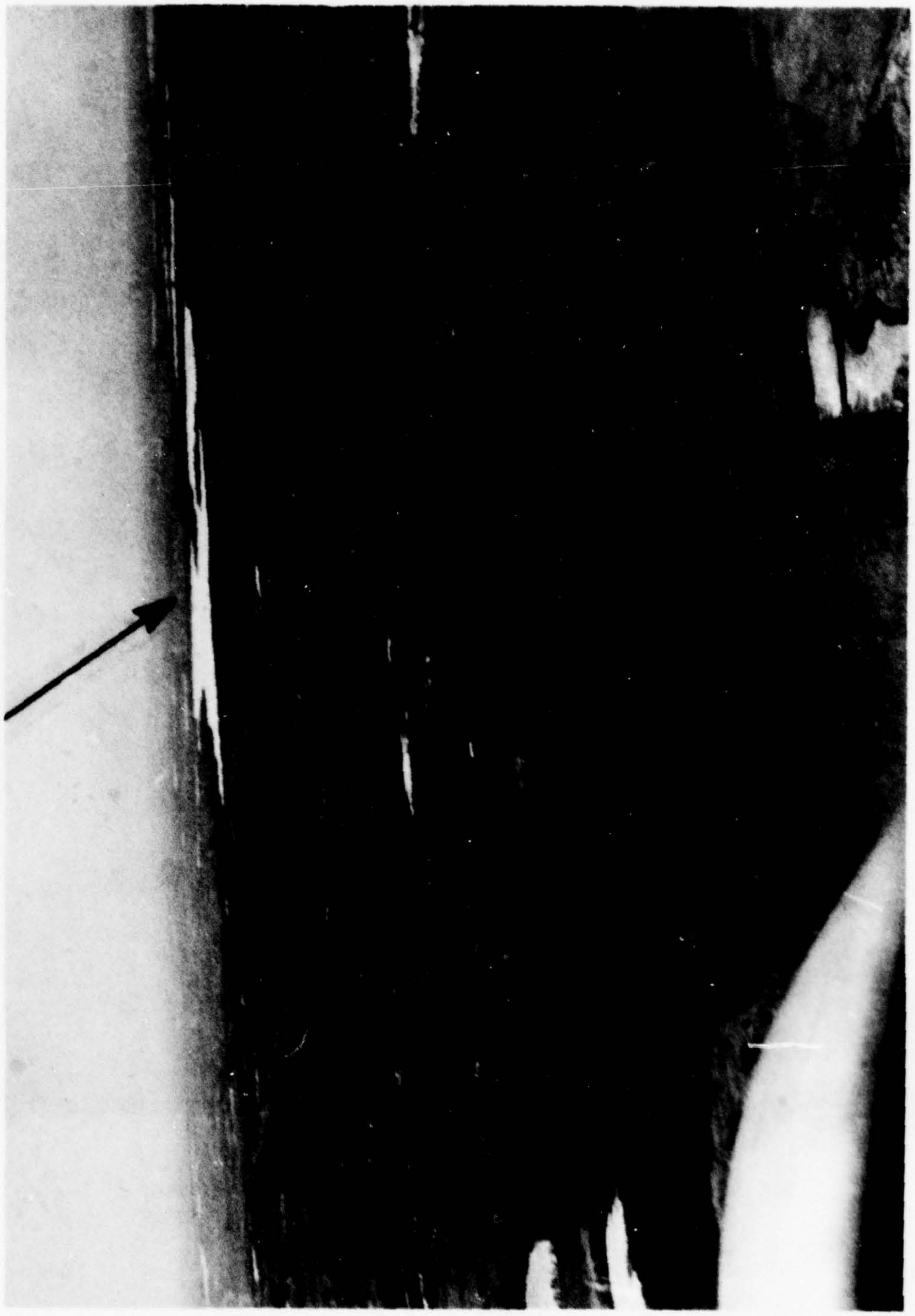


Figure 2-16. Target E Island in White Bear Lake
7 nm Range - Heading 290 deg

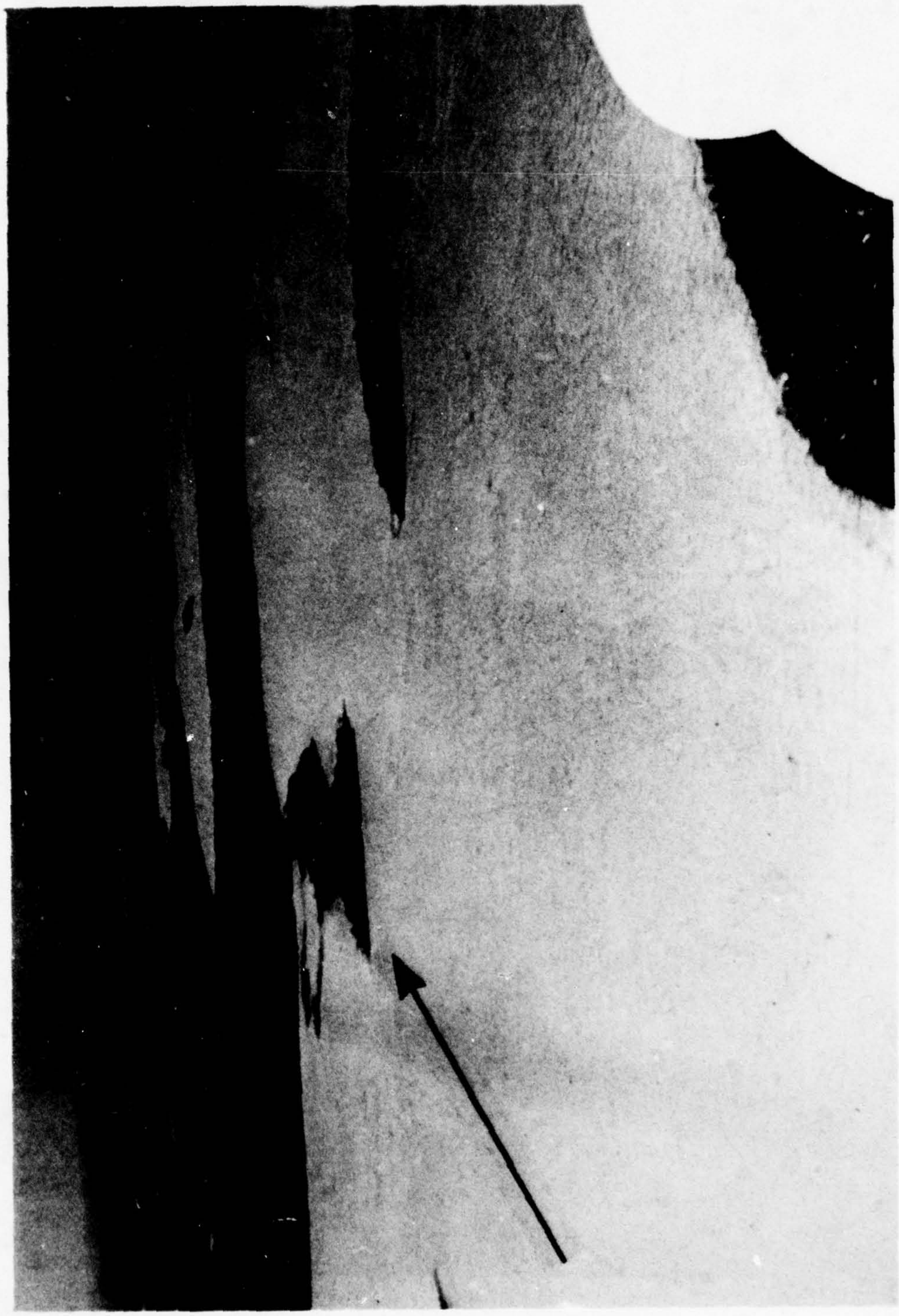


Figure 2-17. Target E Island in White Bear Lake
2 nm Range - Heading 290 deg

Figure 2-18. Target F NSP Stack at Bayport
13 nm Range - Heading 31 deg

Figure 2-19. Target F NSP Stack at Bayport
9 nm Range - Heading 40 deg

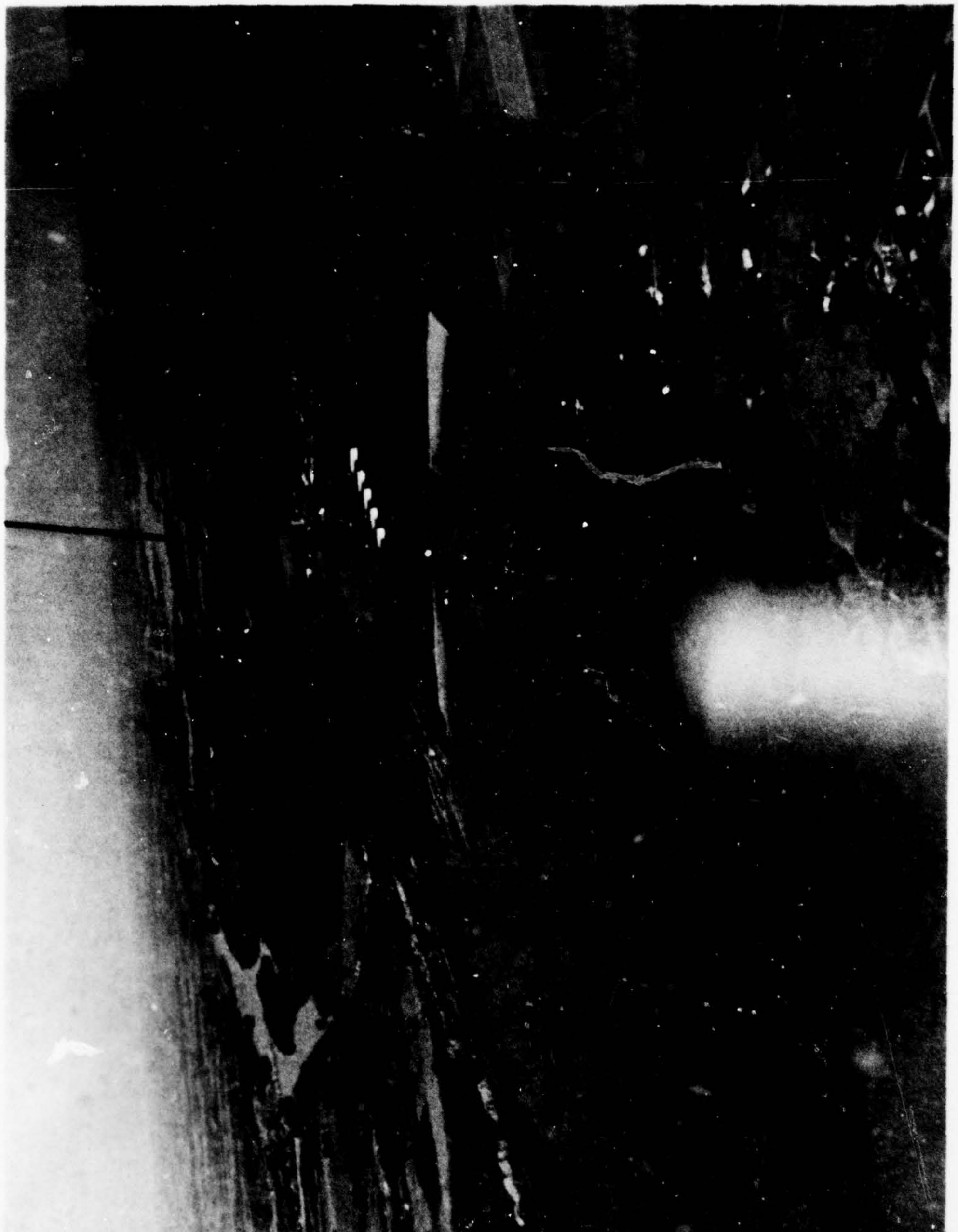


Figure 2-20. Target G Highway Bridge at Hastings
5 nm Range - Heading 116 deg

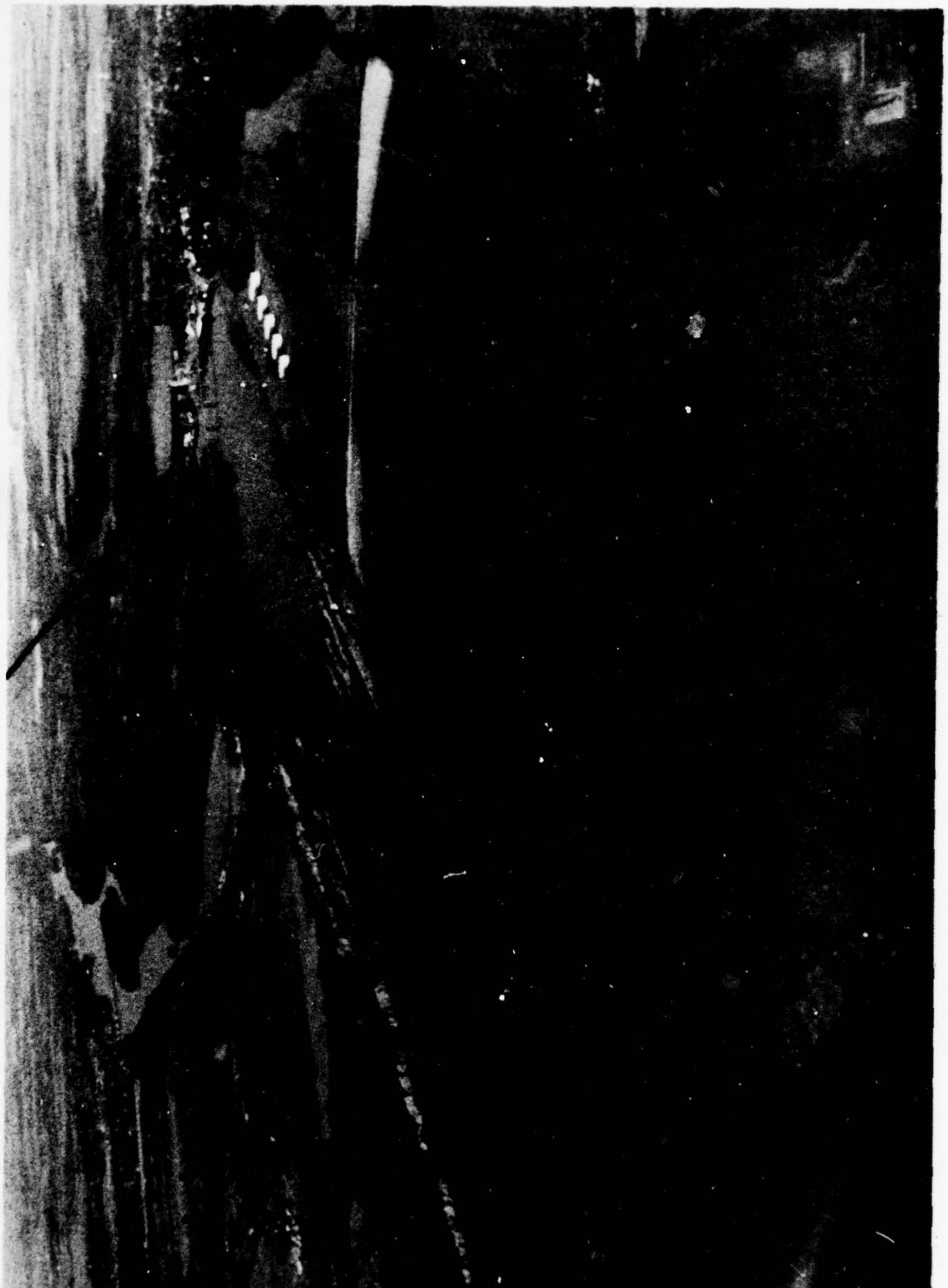


Figure 2-21. Target G Highway Bridge at Hastings
3 nm Range - Heading 116 deg

SECTION III
FLIGHT TEST RESULTS

The work on the gimbal system was started in October 1972 and the first flight was made 4 January 1973. The first half of Phase I of the helmet/sight display flight test program in the Cessna 310 was completed. This includes evaluation of the variables: field of view, altitude, and display brightness. Twenty-two flights were flown in this phase of the testing to evaluate the performance of a helmet-mounted display and also to identify several problem areas. The second half of Phase I will be completed in the second half of 1973.

The major helmet-mounted display design variables to be studied were:

- Visor transmission
- Sensor/display scaling
- Sensor/display rotation gains
- Field of view
- Vertigo and other visual perception phenomena

Since some of these items constituted a greater problem than anticipated, the planned one-week test intervals had to be extended.

The camera, helmet and display were used for about 100 hours in ground operation. During this time, the system was checked out, adjusted, and calibrated for operation in accordance with the test plan. The helmet-mounted display system was used for about 40 hours in airborne operation. It took four flights for a total of four hours to debug the equipment and have it in good working order. There were six demonstration flights for a total of six hours to show the system to various individuals responsible for the helmet sight/display development.

A total of 22 data flights were made in the first phase for a total of 26-1/2 hours. Another five flights were made in eight hours to identify targets and locations for the visual perception phase of the program. Eleven subjects were used in the first phase of the program.

Three of the eleven subjects had a private pilot rating or higher. The remaining subjects were of varying degrees of experience so that disorientation could be expected to be a problem. Only three subjects developed weak headaches or slight nausea, a small percentage of the 22 flights. In fact, this percentage is about what can be expected from normal light plane flying without the task of searching for targets.

The image of the reticle is a pale yellow green and is one-to-one with the real world with respect to size and position. The image is boresighted for an object between two to three miles range with the camera lens set at infinity and the opening at f/16. Many subjects commented that there was no reason to see through with the right eye although this was not being investigated. On several occasions, a tinted transparent glass filter was attached to the outside of the combiner (Figure 3-1). This improved the picture against very bright background and didn't seem to affect the helmet wearer's ability to find the target. An effective combination was a 4 percent visor, a 15 percent filter over the combiner and a 28 percent combiner to give a 0.16 percent total transmission of ambient light to the right eye.

The brightness of the display was acceptable to the observer who wore the helmet display. This brightness was calibrated periodically and expressed in terms of footlamberts. For the majority of the flights the cathode ray tube on the helmet was set for 150 footlamberts at 10 shades of grey but was increased to 300 footlamberts for a few flights. The subjects preferred the 150 footlambert display brightness.

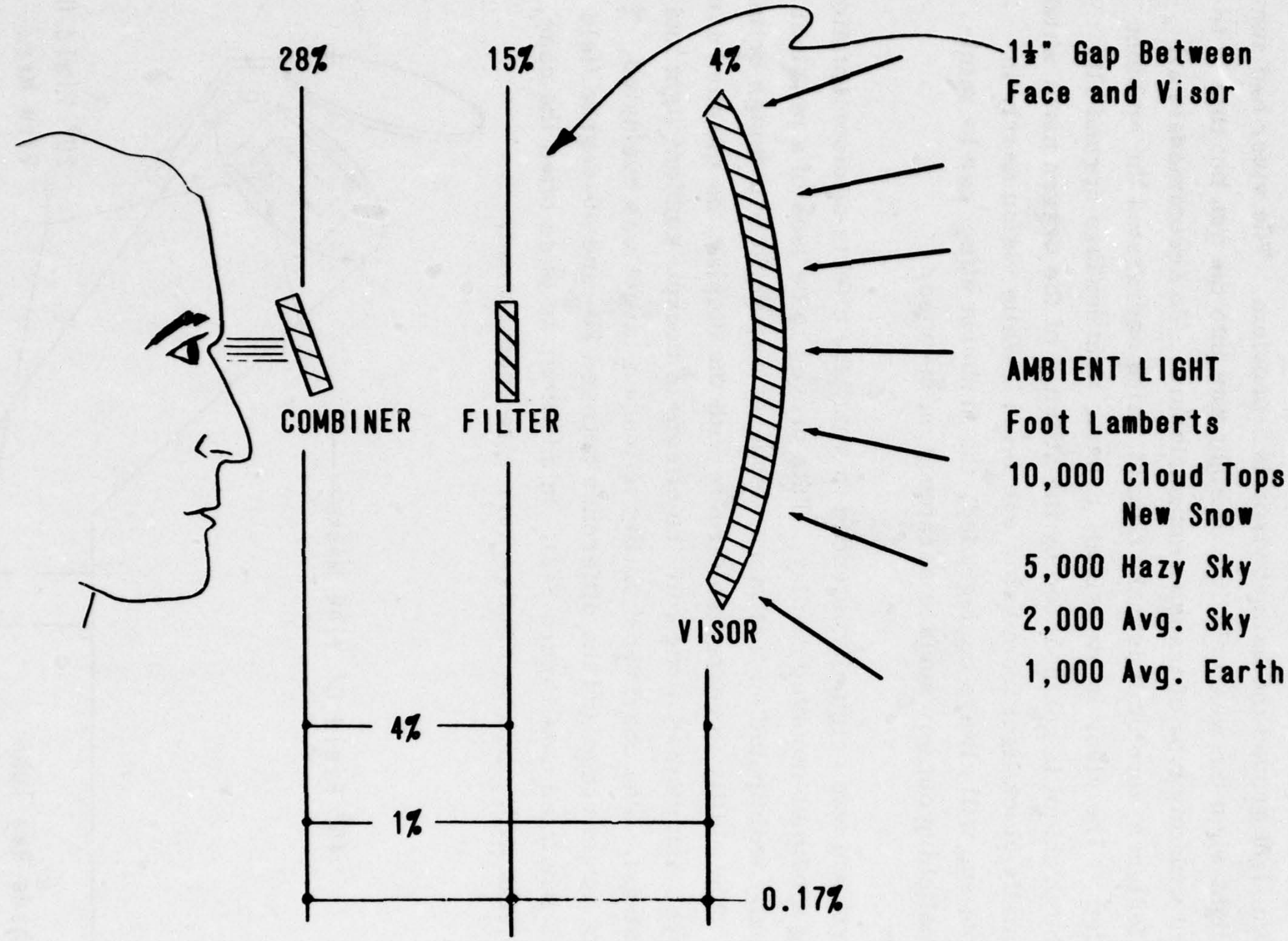


Figure 3-1. Display Optics Schematic

The ambient light around the helmet visor is a problem. The visor had sunbursts of light when the wearer's line of sight was into the sun but this is to be expected with any type of transparent enclosure. To accommodate all subjects, features were built into the helmet which aggravated the ambient light problem. The visor is oversized, causing light leakage around all edges. The problem is compounded by the absence of the oxygen mask which would normally block light from below eye level. While vision nearly in line with the sun will always be degraded, the sunburst effect can be minimized by polishing out any surface scratches on the visor.

The test problem was originally intended to study the effects of disorientation while using a helmet-mounted display. This proved to be less of a problem than originally anticipated so that more emphasis was shifted to design criteria problems. The ability to recognize targets with the display, as mounted over the right eye, was studied along with the effects of cockpit ambient light and display contrast. The observers' ability to track a target was evaluated. The influence of target range and the difference between 20- and 40-degree field of view was tabulated (see Figure 3-2). In addition, as is so often the case, other problems with a helmet display were also encountered.

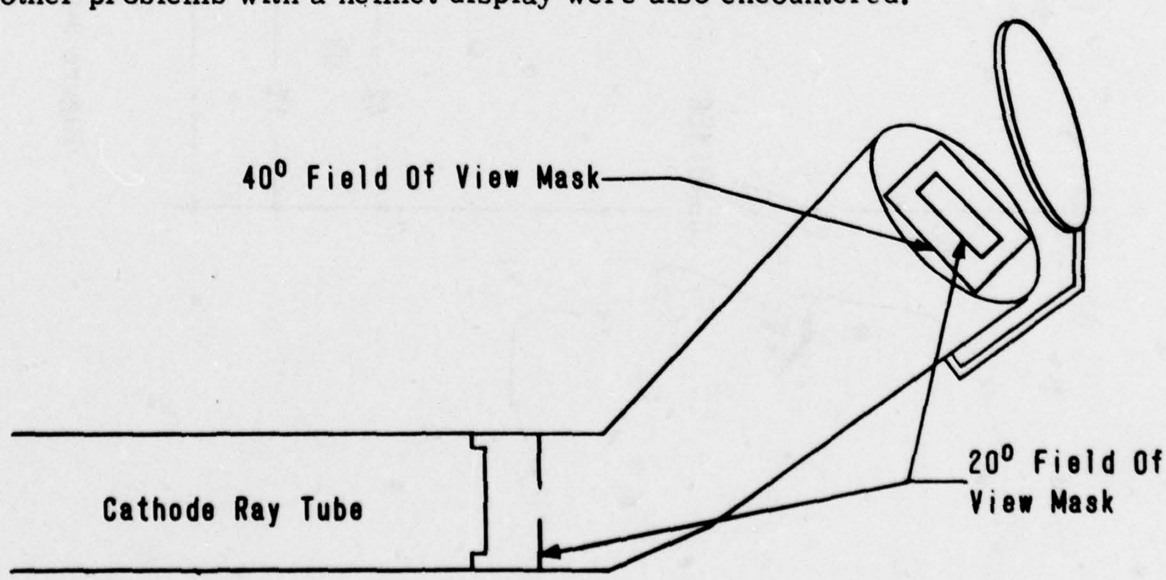


Figure 3-2. 20-Degree and 40-Degree Field of View

If the test had to be flown again, the 20-degree field of view would be flown first to better demonstrate and evaluate the 40-degree field of view which was preferred by all subjects.

The camera dynamics were not a problem although it was a fixed focus, fixed opening system. The focus was set for infinity and the opening was generally f/16. The camera had a gain control that accommodated for various levels of light. The best picture as selected by the subjects is obtained when the line of sight is 20 degrees down from horizontal.

The flights covered the months of March and April during which the weather was often unfavorable. Half of the flights were obtained during a 10-day period in which the visibility was very good. After the last flight, the 2000 series TV camera was sent to another project and was replaced with a new 6150 series COHU camera. At the same time the system's azimuth travel was increased to 180 degrees and other system changes were also made.

The range at which the target was acquired depended on the complexity and contrast of the target, the ground haze and ambient lighting. The clockwise and counterclockwise target approach was used to see if this effect was significant. The lighting of the target does have a significant effect on the range of detection of the target.

After the target had been acquired, tracking was not a problem. There was concern at first that with an attitude system the target tracking would suffer. Position of the line of sight of the helmet is balanced with gimbal position so that the system is an attitude control with rate damping. Maximum rate for this gimbal system was around 25 deg/sec for pitch and azimuth. After operational experience, attitude steering was determined to be satisfactory since the rate of target movement was low.

The operator sitting height and thus his head position in the light envelope, is more important to the system dynamics than the servo response. The sensor surveying unit is a light source that provides a well defined infrared beam that sweeps in vertical motion. When the beam passes the helmet-mounted sensors, signals are produced for mathematical measurement of the helmet line of sight. The sensor system had a limit program built in so that if the helmet sight was moved outside of the preset limits in either axis, the command was cut out in both axes. Quite often the observer would lift his head above the horizon which was outside of the limit in pitch so that both pitch and azimuth were limited. With his head in this position, azimuth movement had no effect until the head was lowered to the horizon limit. This feature gave the picture a very jerky response in the tracking task. This feature was eliminated when the system was down for the new camera installation. A light source was also added on the left side of the test position to accommodate the desired 180-degree azimuth movement. The two light sources will also compensate for the times when the observer tends to shift laterally in the seat towards one sensor. With both sensors now in use the observer will generally stay within the helmet limits.

Both a 20-degree and 40-degree field of view were evaluated with the side-mounted display. There was no apparent effect on target acquisition by the size of the field of view, although all subjects favored the wider field of view.

The effect of lighting on the target is significant since ground haze or heavy cloud cover makes it difficult to find the targets. It is also difficult to express this in terms of light meter readings since the ambient light level may be high for days in which a haze covers the ground. The light meter, being an integrating device only, describes the light between the aircraft and the target. The second phase of the study, now in progress, will concentrate on the human factors aspects such as the clear-versus-photochromic visor and other display and illumination variables. The Phase II test program is described in Appendix B.

A resolution check of the helmet-mounted display was conducted on all subjects before each flight. It is important to get the resolution of the entire system since each component decreases the overall resolution of the system. This resolution check served as the calibration test of this man/machine system.

The resolution chart shown in Figure 3-3 was used to check vertical and horizontal resolution while the aircraft was on the ground. The dark bars are spaced at 1-inch intervals and are 1-inch wide by 18 inches long. In the test, the chart is progressively moved away from the front of the aircraft until the bars can no longer be distinguished from each other. A check is made with the horizontal bars to obtain vertical resolution and with the vertical

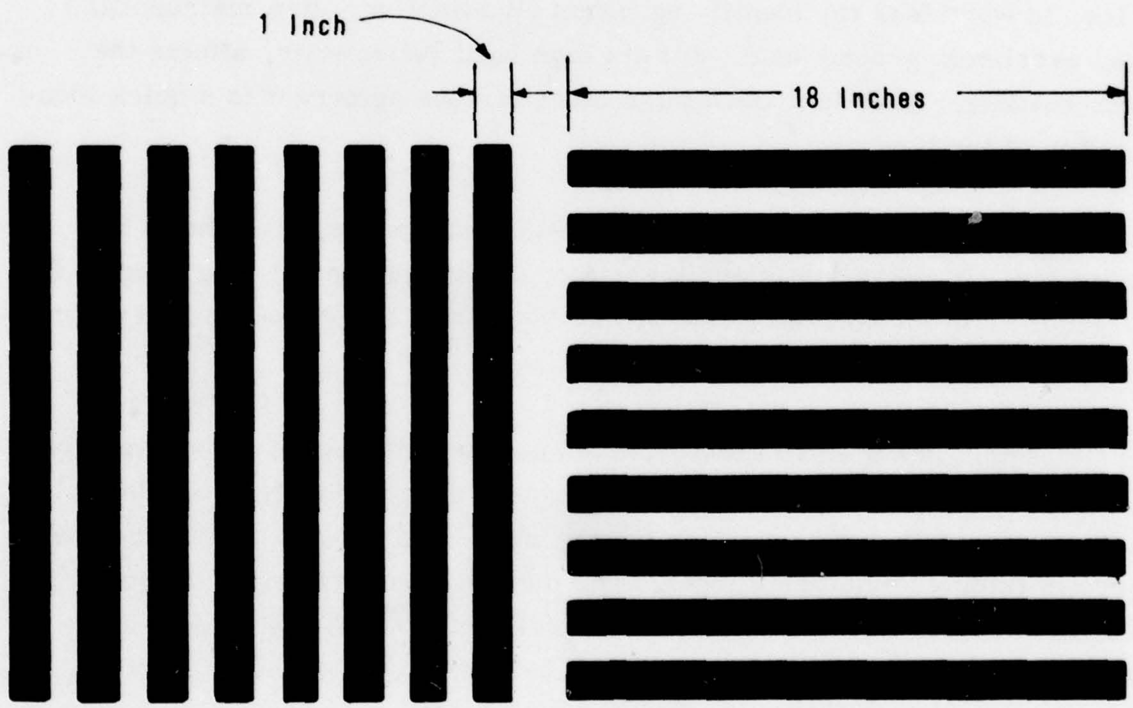


Figure 3-3. Resolution Chart

bars to get horizontal resolution. The light level on the chart is measured by the light meter. The chart is viewed by only the right eye as the projected image on the combiner.

The subjects' average resolution was 5 minutes of arc for the vertical resolution and 4 minutes of arc for the horizontal resolution. The readings were generally grouped within ±1 minute of arc of the average of the group as a whole. These are very good readings and can be verified by the extreme ranges (8 to 10) miles at which some of the targets were detected.

The light meter readings of the targets taken in the air were a disappointment. It was thought that it would be a good method of correlating the results since light level is important. However, the light meter being an integrating device, is worthless for identifying target illumination. In a metropolitan area, persistent ground haze, with its high light reflectivity, affects the meter reading. Haze is probably the most serious deterrent to a quick identification of the target.

The average range of the 11 subjects in acquiring the target is shown in Figure 3-4. It shows that some targets could be acquired at long range. One was acquired at an average range of 1 mile but this target was hidden among trees and was always difficult to find.

The flight plan is shown in Figure 2-7 for either a clockwise or counterclockwise flight. The direction was varied to avoid the possibility of a subject using other clues to detect the target or for the subject to acquire too much experience in finding any single target. The numbers on each leg of the flight plan refer to the separation of targets in minutes of time. These targets are identified further in Figures 2-8 through 2-21.

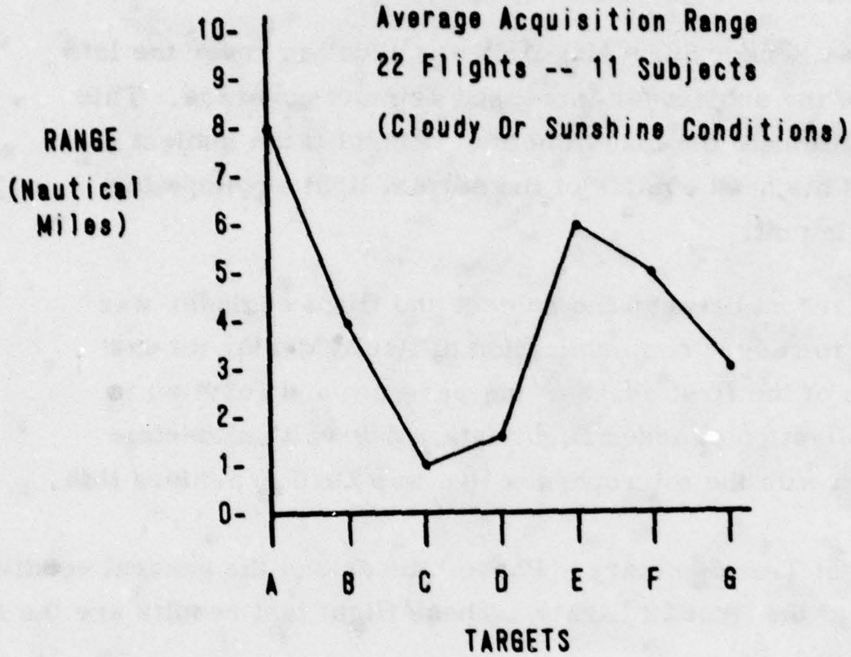


Figure 3-4. *Target Acquisition Range*

IMPROVEMENTS AND RECOMMENDATIONS

The following improvements were accomplished before the human factors flight test Phase II. The recommendations involve modifications to the aircraft installation.

1) The range in azimuth was too restrictive. It was recommended that the azimuth be changed to ±90 degrees. At the same time the servos were changed to a size 18 for azimuth and a size 15 for pitch. This gives the azimuth a rate of around 40 degrees per second which is sufficient to blur the picture. The camera used in these tests was needed on another program so a new COHU 6150 camera was purchased. The size of this camera required changes in the gimbal so other changes were also incorporated.

2) Another Sensor Surveying Unit was added to cover the left side of the subject for increased azimuth coverage. This will eliminate the loss of helmet control if the subject moves his head outside of the normal light envelope for a single unit.

3) An intercom between the subject and flight engineer was added to reduce communication difficulty during the last flights of the first phase of the program and resulted in the collection of added flight data. A 9-volt solid-state system with the microphones live was used to achieve this.

Table 3-1 Flight Test Summary - Phase I describes the general conditions and variables of the first 22 flights. These flight test results are the subject of this report.

Table 3-1. Flight Test Summary - Phase I

Flight Number	Date	Purpose	Display Conditions					Operation Condition		Test Condition	HMD Resolution (Min.)
			FOV (Deg)	Display Brightness (Ft. L.)	% Light Transmission						
					Combiner	Visor	Alt (AGL)	Vel (IAS)	Visibility		
1	8 March 73	Demo	40	> 150	4	100	2000	150	Cloudy	Design Criteria	24
2	12 March 73	Data	40	> 150	0.17	4	2000	150	Clear 30 Miles	Design Criteria	3.5
3	12 March 73	Data	40	> 150	0.17	4	2000	145	Clear Haze 30 Miles	Design Criteria	5
4	12 March 73	Data	40	> 150	0.17	4	2000	155	Partly Sunny Haze 15 Miles	Design Criteria	2 1/2
5	19 March 73	Data	40	150	0.17	4	2000		Clear 30 Miles	Design Criteria	-- --
6	20 March 73	Data	40	150	0.17	4	2000		Clear 15 Miles	Design Criteria	5 6
7	20 March 73	Data	40	150	0.17	4	10000		Clear 30 Miles	Design Criteria	3 4
8	20 March 73	Data	40	150	0.17	4	2000		Clear 30 Miles	Design Criteria	4
9	21 March 73	Data	20	150	0.17	4	2000		Clear 30 Miles	Design Criteria	--
10	22 March 73	Data	20	150	0.17	4	2000		Clear 30 Miles	Design Criteria	6 4
11	22 March 73	Data	20	150	0.17	4	2000		Low Dark Clouds	Design Criteria	6 5
12	23 March 73	Data	20	150	1.0	4	2000		Clear Haze	Design Criteria	4 3 1/2
13	23 March 73	Data	20	150	1.0	4	2000		Dark Haze	Design Criteria	--
14	26 March 73	Demo	20	150	1.0	4	2000		Partly Cloudy	Demo	--
15	26 March 73	Data	20	150	1.0	4	2000		Cloudy 5 Miles	Design Criteria	5 4
16	27 March 73	Data	20	150	1.0	4	2000		Cloudy Haze 5 Miles	Design Criteria	5.7 5.0
17	27 March 73	Demo	20	150	1.0	4	2000		Cloudy 5 Miles	Design Criteria	-- --
18	28 March 73	Data	20	300	1.0	4	2000		Partly Cloudy 10 Miles	Design Criteria	5 4
19	29 March 73	Data	20	300	1.0	4	2000		Partly Sunny 10 Miles	Design Criteria	-- --
20	30 March 73	Data	20	300	1.0	4	2000		Partly Sunny 5-10 Miles	Design Criteria	6 8
21	30 March 73	Data	40	300	1.0	4	3000		Partly Sunny 10-15 Miles	Design Criteria	4 4 1/2
22	30 March 73	Data	40	300	1.0	4	3500		Partly Sunny 15 Miles	Design Criteria	5 7

SECTION IV
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The most important conclusion obtained from the flight test was the absence of any significant spatial disorientation effects. The percentage of subjects with any feeling of nausea or headache was about that expected on typical commercial small plane flights. The Phase II tests will provide an objective measure of disorientation effects and vertigo to supplement the Phase I results.

Tracking a target, once it was acquired, was not a problem. An attitude feedback was used to drive the camera to follow helmet sight inputs but helmet rate feedback might have been used instead. The attitude feedback provided good tracking ability with a rate signal added for damping.

The range from the target had little effect since acquisition of the target depended on target contrast and ground haze. This conclusion may be different if the camera had a zoom lens instead of the fixed lens. For these studies it can only be concluded that range had no effect within the total resolution limits of the system, $\approx 5 \ \widehat{\text{min}}$. The 20-degree field of view was adequate for the Phase I studies although all subjects preferred the wider, 40-degree field of view.

The contrast between the picture seen by the right eye on the combiner and the outside world seen by the left eye through the visor is a problem. The problem is reduced with a filter on the outside of the combiner. With the

visor down, the contrast is acceptable; although, like the 20- and 40-degree field of view, a little more is always preferred. The difference in light intensity to the left and right eye should be less than a factor of 10.

The targets selected seemed to be representative of the type of targets that the military may have to detect with a helmet sight system. The contrast and lighting is very important in picking up the sites but no new or startling method to detect targets was found.

RECOMMENDATIONS

1) For the second phase it is recommended that pilots be used as subjects to further study the disorientation problem. The objective should be to complete the tasks during various types of maneuvers and in some way measure the degree and extent of possible disorientation. The result obtained in Phase I with subjects not qualified as pilots is already encouraging and Phase II should confirm these results and complete the study.

2) A design aim of 45 degrees per second should be used for the azimuth servo and the pitch servo even though the TV picture is a blur at this rate. For further programs, the 180-degree coverage in azimuth should be sufficient as well as the 45 degrees in pitch.

3) The target contrast is a problem and more work should be done on the visor and the combiner glass. With the head down the contrast is acceptable but becomes marginal when viewed against a snow background or against white clouds.

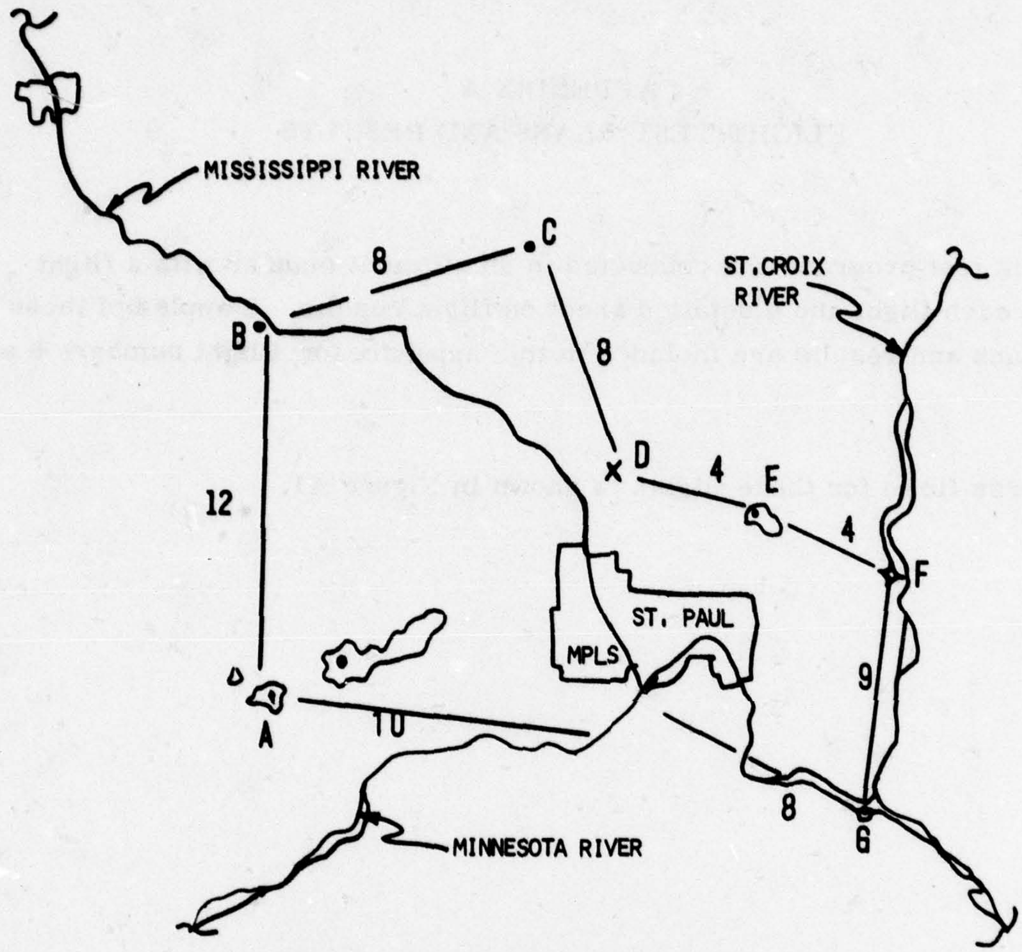
4) A similar type program should be flown at night with a low-light-level TV camera. A person searching the ground for targets at night would be hampered by the light level of a monitor in the

aircraft. If it were necessary to refer to the real world scene for further target identification it would take some time for the eyes to accommodate to the light level. With a helmet mounted display, the image would enhance the real world scene with greater detail without "flooding" the eyes with light.

APPENDIX A
FLIGHT TEST PLANS AND RESULTS

The flight test program was conducted in an efficient manner with a flight plan for each flight and a detailed sheet on flight results. Samples of these flight plans and results are included in this appendix for Flight numbers 6 and 12.

The course flown for these flights is shown in Figure A1.



HELMET DISPLAY FLIGHT PLAN

A	ISLAND IN LAKE WACONIA
B	NSP STACK AT MONTICELLO
C	HOPG AT ST. FRANCIS
D	ANOKA COUNTY AIRPORT
E	ISLAND IN WHITE BEAR LAKE
F	NSP STACK AT BAYPORT
G	BRIDGE AT HASTINGS

Figure A1. Target Locations

CESSNA 310 FLIGHT TEST PLAN

FLIGHT NUMBER: #6 PILOT: Jim Magnus

DATE: 3-20-73

OBSERVERS: G. Hedges
B. Olson

OBJECTIVE:

To measure operator performance with HMD. To gather data on 40° FOV display.

FLIGHT PLAN:

Counterclockwise to Hastings first, on course as marked in test plan. 150K IAS, 2000 ft. AGL.

FLIGHT CONDITIONS:

Clear, dark haze on horizon limit visibility 15 miles.

CESSNA 310 FLIGHT TEST RESULTS

FLIGHT NUMBER: #6 PILOT: Jim Magnus

DATE: 3-20-73

OBSERVERS: G. Hedges
B. Olson

OBJECTIVE: To measure operator performance with HMD. To gather data on 40° FOV display.

FLIGHT PLAN: Counterclockwise to Hastings first, on course as marked in test plan. 150 K IAS, 2000 ft. ACL.

FLIGHT CONDITIONS: Clear, dark haze on horizon limit visibility 15 miles.

Start Eng. 9:38 Takeoff: 9:45 Land 11:00 Total 1:22

Depart G	9:55	155 KIAS 3000 Alt. went over bridge Range 01:30 02:30 total
Depart F	10:04	Can see stack from 1 mile south of Hastings Can see stack on Monitor from St. Croix Beach Range 03:30 05:13 total
Depart E	10:08	155 KIAS, 3000 ft. Range 02:30 02:45 total
Depart D	10:13	Range 0:42
Depart C	10:23	Range abeam 01:16 total Can see Monticello from C
Depart B	10:30	Range 02:00 02:30 total

Depart A Range 03:42 05:36 total

Depart rr bridge 10:53 Range 0:46 0:46 T

Visibility 15 nm

FLIGHT #6 COMMENTS AND RESULTS G. Hedges 40° FOV

- Pitch axis was restored by replacing pitch servo amp prior to takeoff.
- Feels it is a one-to-one image (versus real world).
- Images didn't superimpose.
- Had to shut one eye to get the target - to acquire target at range.
- After target acquisition - detail on image (projected) was good enough to over power the left eye. (Right eye of subject is stronger than the left eye.)
- There is no reason for see-through on right eye.
- May have been concentrating on detection (∴ target was acquired at longer range than previous subjects).
- Rules of the "game" and criteria should have been explained better.

Target	Range (n.m.) to Target	GS	Time on Target	Comments
G	10	(155) 232 fps	90 sec R 150 sec T	
F	8	(155)	210 sec R 213 sec T	
E	4	(155)	150 sec R 165 sec T	
D	5	(155)	42 sec R	
C	10	(155)	Detected target when abeam 76T	
B	7	(155)	120 R 150 T	

Target	Range (n.m.) to Target	GS	Time on Target	Comments
A	--	(155)	222R 636 T	
RR Bridge	--	(155)	46R	

Horizontal line resolution 47 ft. ≈ 6 min
Vertical line resolution 60 ft. ≈ 5 min
Inside the Hangar

CESSNA 310 FLIGHT TEST PLAN

FLIGHT NUMBER: #12 PILOT: Jerry King

DATE: 23 March 1973

OBSERVERS: Jim Kelly
B. Olson

OBJECTIVE:

To measure operator performance with HMD. To gather data on 20° FOV display, with 1% transmission combiner.

FLIGHT PLAN:

Clockwise: Lake Waconia first and autobridge at Hastings last. Course as marked in test plan. 150 MPH IAS 2000 ft. AGL.

FLIGHT CONDITIONS: High thin overcast
Bright Haze
Visibility officially 10 miles
(more like 5 actual) wind 150°/15 kts

CESSNA 310 FLIGHT TEST RESULTS

FLIGHT NUMBER: #12 PILOT: Jerry King

DATE: 23 March 1973

OBSERVERS: Jim Kelly
B. Olson

OBJECTIVE: To measure operator performance with HMD. To gather data on 20° FOV display, with 1% transmission combiner.

FLIGHT PLAN: Clockwise: Lake Waconia first and autobridge at Hastings last. Course as marked in test plan. 150 MPH IAS 2000 ft AGL.

FLIGHT CONDITIONS: High thin overcast
Bright haze
Visibility officially 10 miles
(more like 5 actual) wind 150°/15 kts

TCA 3/23/73 Start Eng. 10:28 Takeoff: 10:39 Land: 12:02

Wind 150°/11R clear haze 5 miles or less

Depart A 10:54 01:09R 01:09T
150 IAS MPH
Visor has bright spots of light which bothers left eye.
2900 ft

Depart B 11:06 0:95R 0:95T
Wind 90°/5K

Depart C 11:13 Edges of Big Lake Visibility 5 miles bright haze
0:15R got at about 45° LOS

Depart D	11:24	Visibility 3 miles bright haze 0:30R	
Depart E	11:28	0:36R	
Depart F	11:32	0:38R	Visibility 5 miles, bright haze
Depart G	11:42	0:38R	Visibility 5 miles

FLIGHT NUMBER: #12 Results and Comments

Jim Kelly - 2000 clockwise

- 20° FOV, 1% transmission
- 20° FOV didn't affect performance.
- Need a bit more focus adjustment on the display. It seemed a bit fuzzy.
- Visor had bright spots which were seen in left eye and transposed to the right eye view. Spots went away on closing left eye. Visor appeared dirty (was cleaned before next flight).
- Edges (shore line) by Big Lake appeared fuzzy at about 4 miles; became sharp at 3 miles.
- The haze had a detrimental effect on display resolution.
- No visual, head or stomach problems.

Target	Range n.m. to Target	GS	Time on Target	Comments
A	14	(155) 232 fps	109R sec	
B	12	(160) 240 fps	95R sec	Wind 90°/6K
C	7	(148) 222 fps	15R sec	Got target at LOS = 22°
D	9	(140) 210 fps	30R sec	Visibility 3 miles into sun
E	4	(142) 212 fps	36R sec	
F	4	(143) 213 fps	38R sec	

Target	Range n.m. to Target	GS	Time on Target	Comments
G	10	(142) 212 fps	38 R sec	Visibility 5 miles

Resolution On Ramp $\begin{cases} 72' \approx 4\ \widehat{\text{min}}\ \text{(horizontal line fade)} \\ 83' \approx 3\text{-}1/2\ \widehat{\text{min}}\ \text{(vertical lines fade)} \end{cases}$

APPENDIX B
HMS/D VERTIGO DISORIENTATION FLIGHT TEST PLAN

INTRODUCTION

The Phase II flight program is complete. The data are being analyzed and complete results will be presented in detail in a separate report. The Phase II program followed the test design described below except that only four subjects were used instead of the eight originally planned. Table B1 summarizes the purpose and display, operational, and test conditions applicable to each flight.

Four professional pilots were tested. One subject reported some discomfort on one flight. He had however also reported a slight upset condition before the test flight. Therefore, within the constraints of the aircraft performance capability and the test design, vertigo and other spatial disorientation effects are not a problem with a see-through helmet mounted display.

Generally, in flight, the pilot can compare the reports from all his senses and learn his true attitude. However, when visibility is "limited" the pilot cannot test his sensations by what he sees. The various sensations can mislead him completely and cause vertigo, the symptoms of which are dizziness and attitude disorientation.

Vertigo/disorientation can be described as a psychophysiological state of anxiety, confusion, and panic which results from the loss of a firm frame of reference. The data from published vertigo/disorientation research have been obtained from:

Table B1. Flight Test Summary - Phase II

Flight Number	Date	Purpose	Display Conditions				Operation Condition			Test Condition	HMD Resolution (Min)
			FOV (Deg)	Display Brightness (Ft. L.)	% Light Transmission						
					Combiner	Visor	Alt (AGL)	Vel (IAS)	Visibility		
23	3 April 73	Debug	40	150	1.0	4				--	--
24	3 April 73	Debug	40	150	1.0	4				--	--
25	4 April 73	Debug	40	150	1.0	4				--	-
26	5 April 73	Debug	40	150	1.0	4				--	--
27	5 April 73	Debug	40	150	1.0	4				--	--
28	17 April 73	Orientation & Data	40	150	0.5	13	4000	160	Clear 30	IFR_1	4 1/2 3 1/2
29	18 May 73	Orientation & Data	40	150	No Display	Hood	4000	160	--	IFR_1	3.5 3
30	18 May 73	Data	40	150	No Display	13	4000	160	Clear Haze 15	VFR_1	3 1/2 3
31	21 May 73	Orientation & Data	40	150	0.5	13	2000	160			
32	29 May 73	Data	40	150	No Display	13	4000	160	Clear 30	VFR_1	--
33	4 June 73	Equipment Debug	40	150							
34	5 June 73	Equipment Debug	40	150							
35	5 June 73	Equipment Debug	40	150							
36	7 June 73	Orientation Data	40	150	Aircraft abort at first target						
37	8 June 73	Data	40	150	0.15	13	4000	160	Partly Sunny Haze 6 Miles	VFR_2	3 1/2 3
38	8 June 73	Data	40	150	0.15	Hood	4000	160	Haze 30 Miles	IFR_2	--
39	11 June 73	Data	40	150	0.15	13	4000	150	Clear Bright Haze 15 Miles	IFR_2	5 3 1/2
40	12 June 73	Data	40	150	0.15	13	4000	160	Thin Clouds Bright Haze 20 Miles	VFR_2	4.0 3 1/2
41	12 June 73	Orientation & Data	40	150	0.15	13	4000	160	Clear 20 Miles	VFR_2	5 4
42	13 June 73	Data	40	150	0.15	Hood	4000	150	Unlimited	IFR_2	4 1/2 3 1/2
43	13 June 73	Data	40	150	No Display	Hood	4000	150	Unlimited	IFR_1	--
44	13 June 73	Data	40	150	No Display	13	4000	145	Clear 25	VFR_1	4 1/2 3 1/2
45	14 June 73	Data	40	150	0.15	Hood	4000	150	Unlimited	IFR_2	4 1/2 3 1/2
					0.15	13	4000	150	Unlimited	VFR_2	
46	14 June 73	Data	40	150	No Display	13	4000	160	Haze/30	VFR_1	--
					No Display	Hood	4000	150	Haze/20	IFR_1	--
47	15 June 73	Demo	40	150	0.15	13	2000	150	Cloudy 5 Miles	IFR_2 VFR_2	--
48	15 June 73	Data/Abort	40	150	0.15	Hood	4000	160	--	IFR_2	--
49	28 June 73	Light Measurement	N.A.	N.A.	N.A.	N.A.	2000	160	Cloudy 10	--	--
50	28 June 73	Light Measurement	N.A.	N.A.	N.A.	N.A.	4000	160	Partly Sunny 20	--	--

•	Subjective reports Rating scales questionnaires	80%
•	Performance decrement measures	15%
•	Electrophysiological measures	5%

The mechanisms of vertigo/disorientation are:

1) Vision

2) Non-auditory labyrinth

3) Kinesthetic senses

4) Psychological state (anxiety)

Vertigo/disorientation has been associated with the sensations of instrument flying. A common example occurs when the horizon is not visible. The pilot sometimes takes the line of clouds as the horizon and banks the aircraft to match the slope of the clouds. The solution to the disorientation problem for instrument flying is to ignore the "normal" sensations and to depend on the instruments' readings and to act on that information automatically.

The following data indicate when vertigo/disorientation may occur:

•	Instrument flight (transition VFR to IFR)	60%
•	Night flight	20%
•	Maneuvering flight	10%
•	Miscellaneous flight conditions	10%

(Based on 1020 incidents investigated, Freud 1972)

Categories of vertigo/disorientation are:

1) States of confusion

- Geographic disorientation
- Time reference

2) Disturbances of equilibrium

- Oculogyral illusion (angular acceleration)
- Oculogravic illusion (linear acceleration)
- Change in pressure
- Head movement (Coriolis effect)

3) "Fascination"

- Hypnogenic states

4) Visual illusions

- Autokinesis
- Flicker
- Optical illusions particular to flight environment
  - slanted cloud banks
  - lack of horizon reference

The HMS/D provides the pilot with the ability to acquire targets by merely looking at them. It provides a direct visual feedback via a unique visor - projected CRT display. This device introduces another image into the pilot's field of view. The following considerations are a part of the HMS/D vertigo/ disorientation experiment design:

- The image projected to the HMS/D user is stabilized with respect to his line of sight (the image moves when he moves his head).

- Vertigo and disorientation are frame of reference problems.

SUMMARY

The subject, with and without an HMS/D under IFR and VFR conditions, will attempt to find specified ground targets while the airplane traverses a closed course beginning and ending at the Honeywell hangar. During flight, various maneuvers and head movements will occur in an attempt to induce vertigo/disorientation. We will then measure vertigo/disorientation based on performance decrements and subjective reports, and relate to the experimental conditions.

TEST PLAN

The test plan is to use the Cessna 310 aircraft as the test bed. It will be configured with the TV sensor system used in Phase I. The aircraft will be flown over typical ground targets which the subject will locate and track while the aircraft is maneuvered in a specified sequence.

The subjects will be professional pilots who are instrument rated in fixed wing and/or rotary wing aircraft. They will be representative of Air Force pilots in experience, physical condition and visual capability.

The aircraft will be flown over the designated targets in such a manner as to reduce the effects of weather, haze and target lighting.

The measure of performance will be the time required for the subject to re-acquire the target after the aircraft maneuver sequence is completed. All of the subjects' comments inflight will be recorded on tape. Other tasks will be performed by the subject to measure his orientation. For example, he will designate local vertical at least once during each aircraft maneuver sequence.

Table B2 describes experimental conditions for the flight test. Expected results of the study are depicted in Figure B2. Table B3 describes the maneuver sequences that will be used on each leg of the test course. These are a series of turns that are shallow (20-30 deg bank angle) or steep (45 deg bank angle). Table B4 describes the courses over which the flight tests will be conducted while Table B5 describes the flight sequence counter balancing for test conditions. The maneuver sequence for each leg of the course versus the flight number is described in Table B6. Table B7 describes the target group sequence counterbalancing. Table B8 describes the direction of flight over the designated test course. Since only four subjects were used, only the first four lines of Tables B5 through B8 apply.

Table B2. Experimental Condition

Treatments	Levels
Subjects	8
Conditions of flight • Unaided vision • HMS/D	IFR_1 IFR_2 VFR_1 VFR_2
Aircraft Maneuvers	7 groups of 3 maneuvers plus head movement
Ground Targets	3 groups of 7 targets
Direction of flight	Clockwise or Counter-Clockwise

IFR_1 = No see-out condition
IFR_2 = TV image display only
VFR_1 = See out (no image display)
VFR_2 = See out and TV image

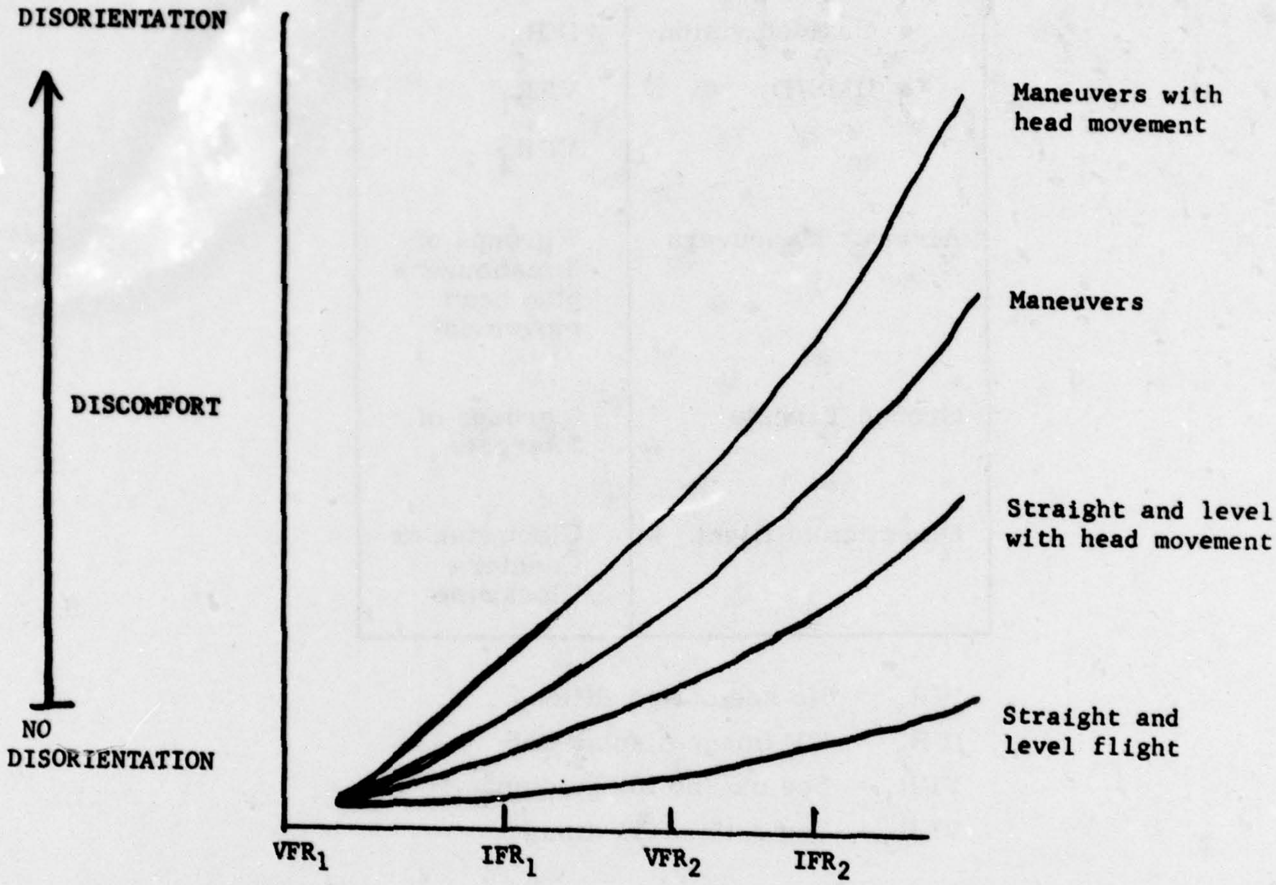


Figure B2. Expected Strength of Induced Vertigo

Table B3. Maneuver Sequences

A	90° right turn 90° left turn 360° turn to the left
B	90° left turn 90° right turn 720° right turn
C	Figure 8 turn along ground track 90° right turn (steep) 90° left turn (steep)
D	Figure 8 turn perpendicular to track 90° left turn 90° right turn
E	45° left turn (steep) straight and level 15 seconds 90° right turn (steep) straight and level 15 seconds 45° left turn (steep)
F	90° left turn (steep) 180° right turn (steep) 90° left turn (steep)
G	Figure 8 perpendicular to track 90° right turn 90° left turn

Table B4. Checkpoints for Acquisition by Subjects

Subject will be required to:

1) Search for and acquire one check point
2) Mark his position every three minutes

Check points are defined as major landmarks readily observed by a standard observer at flight altitude and "standard weather conditions".

For three experimental conditions x 7 legs = 21 checkpoints on course. Three sets of checkpoints, one for every flight/subject.

	(1)	(II)	(III)
	Checkpoint Set 1	Set 2	Set 3
1.	Island-Lake-Waconia	Airport-Flying Cld.	Chaska-City of
2.	NSP Tower-Monticello	Delano-City of	Buffalo-City of
3.	HopG-St. Francis	Elk River-City of	Flynn-City of
4.	Anoka-City of	Soderville-City of	Coon Lake
5.	Island-White Bear Lake	Airport-Northport	Stillwater-City of
6.	Lake St. Croix-City	Hudson-City of	Cottage Grove
7.	Airport-So. St. Paul	Drivein/Road	Bridge at Hastings

Table B5. Flight Sequence Counter-Balancing
(One Condition per Subject per Flight)

Subject	Test Condition			
	IFR_2	IFR_1	VFR_1	VFR_2
1	1	2	3	4
2	2	3	4	1
3	3	4	1	2
4	4	1	2	3
5	4	3	2	1
6	3	2	1	4
7	2	1	4	3
8	1	4	3	2

	Frequency Tabulation				
	1	2	3	4	Σ
IFR_1	2	2	2	2	8
IFR_2	2	2	2	2	8
VFR_1	2	2	2	2	8
VFR_2	2	2	2	2	8
					32

Table B6. Maneuver Sequence Counter-Balancing

Subject	Flight 1							Flight 2							Flight 3							Flight 4						
Leg	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
1	A	B	C	D	E	F	G	A	C	B	F	E	D	G	A	D	B	E	C	F	G	A	D	B	F	C	E	G
2	A	C	D	E	F	B	G	A	B	F	E	D	C	G	A	B	E	C	F	D	G	A	F	B	E	C	D	G
3	A	D	E	F	B	C	G	A	B	D	F	C	E	G	A	B	F	E	D	C	G	A	B	E	C	D	F	G
4	A	E	F	B	C	D	G	A	D	F	C	E	B	G	A	C	F	D	B	E	G	A	E	C	D	F	B	G
5	A	F	B	C	D	E	G	A	F	C	E	B	D	G	A	B	F	C	E	D	G	A	C	D	F	B	E	G
6	A	F	E	D	C	B	G	A	C	E	B	D	F	G	A	F	C	E	D	B	G	A	D	F	B	E	C	G
7	A	E	D	C	B	F	G	A	E	B	D	F	C	G	A	C	E	D	B	F	G	A	D	C	E	B	F	G
8	A	D	C	B	F	E	G	A	F	D	B	E	C	G	A	F	D	B	F	C	G	A	C	E	B	F	D	G

Frequency Tabulations

	Flight					Leg						
	1	2	3	4	Σ		2	3	4	5	6	Σ
B	8	8	8	8	32	B	6	6	7	7	6	32
C	8	8	8	8	32	C	7	7	6	6	6	32
D	8	8	8	8	32	D	7	6	6	6	6	32
E	8	8	8	8	32	E	6	7	7	6	6	32
F	8	8	8	8	32	F	6	6	6	7	7	32
					160							160

Table B7. Target Group Sequence Counterbalancing

Flight				
S	1	2	3	4
1	X	I	II	III
2	II	X	III	I
3	III	I	X	II
4	III	II	I	X
5	II	III	I	X
6	I	III	X	II
7	I	X	II	III
8	X	II	III	I

NOTE: X = IFR_1 Condition (No Targets)

Frequency Tabulation Flight					
	1	2	3	4	Σ
Tgt. I	2	2	2	2	8
II	2	2	2	2	8
III	2	2	2	2	8

Table B8. Direction-of-Flight Counterbalancing

S	1	2	3	4
1	CW	CCW	CW	CCW
2	CW	CCW	CCW	CW
3	CCW	CW	CCW	CW
4	CCW	CW	CW	CCW
5	CW	CW	CCW	CCW
6	CCW	CCW	CW	CW
7	CW	CCW	CW	CCW
8	CCW	CW	CCW	CW

CW = Clockwise
CCW = Counterclockwise

DATA ANALYSIS

Determination of whether or not the HMS/D induces vertigo/disorientation in the airborne environment will be attempted using the following dependent measures:

1) Verbal report of vertigo/disorientation incidence
   a) Occurrence/frequency
   b) Description of type/characteristics/duration
   c) Some indications of intensity
   d) Relate to maneuver/condition

2) Percentage checkpoints acquired
   a) Relate to experimental condition
   b) Relation to vertigo/disorientation

3) Post hoc questionnaire
   a) Type of symptomatology
   b) Opinions on system use, i.e., vertigo/disorientation

4) Subject experience survey
   a) Background data on subjects
      - Navigation ability
      - Airborne experience
      - Predisposition to vertigo/disorientation

5) Borden & McGrath geographic orientation measure
   a) What can we gain versus load on experimenter

TEST CONSTRAINTS

There are problems associated with and constraints upon vertigo/disorientation experimentation summarized as:

1) Airborne test bed (Cessna 310)
   - Limited visibility
   - Limited maneuver loads
   - Limited auxiliary equipment
   - Safety requirements for flight
     - Only Honeywell pilot
     - No flight in IFR conditions
     - Limited maneuvers
     - No night flight

2) Aircraft and pilot scheduling
   - Aircraft shared with marketing
   - Limited time for experimentation
   - Pilot availability
   - Aircraft mantenance schedule
   - Weather

3) Subjects: Honeywell corporate pilots not available
   - Alternatives

4) Auxiliary equipment
   - No physiological capability
   - Limited data recording apparatus
     - Video tape
     - Events recorder
   - Lack of "simulation facility" between HMS/D apparatus and real life uses

5) Financial

- There are significant costs to operate the aircraft over the test period.

The problems associated with the presented test design are:

1) Artifactural relationship between decrease in checkpoints acquired and smaller field of view in the IFR (helmet sight) condition.

2) Partitioning use of outside view (through visor) and HMS/D view in VFR_2 condition.

3) Effectiveness of verbal protocols given the extremely noisy cockpit environment.

4) Relating occurrence of vertigo/disorientation incident to flight time/maneuver etc.

5) Are flight maneuvers adequate for producing vertigo/disorientation?

6) Do we have adequate control over the conditions producing vertigo/disorientation?

7) Are our measures of vertigo/disorientation adequate?

8) Have we overloaded the experimenter's task?

9) Should we reduce the scope of the experiment to fit the field test environment? Do we compromise validity if we do?

10) Is the experimental test bed (Cessna 310) adequate?

11) Is the test plan responsive to the purpose of the IHMS/D program?